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THOMAS HAWKSLEY.

(1807—1893.)

President 1876—1877.

THOMAS HAWKSLEY, F.R.S., was born at Arnold, near Nottingham, on 12th July 1807. After being educated at the old Grammar School, Nottingham, he was articled to Mr. Staveley, an Architect and Surveyor in that town, with whom he subsequently entered into partnership together with Mr. Jalland, as Engineers, Architects, etc. He continued to practise there until 1852, when he removed to London. In 1830 he undertook the construction of the Trent Waterworks on behalf of a Company afterwards known as the Nottingham Waterworks Co., and in connection therewith was the first to introduce into Great Britain the principle of constant supply. This led to his becoming associated as engineer with a large number of waterworks at home and abroad. He also directed the laying out of extensive main drainage and gas works for various towns. His wide experience was in frequent requisition in arbitrations and before parliamentary committees.

Mr. Hawksley became a Member of this Institution in 1856, was elected a Member of Council in 1862, a Vice-President in 1868, and occupied the Presidential Chair in 1876-1877. During the latter period of his Presidency the removal of the Institution from Birmingham to London was effected. His death took place on 23rd September 1893.

Taken August 1882. *Chalkley, Gould and Co. (Successors to Adams and Stillard).*

T Hawksley

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The Institution of Mechanical Engineers.

PROCEEDINGS.

October 1913.

The first Ordinary General Meeting of the Session was held at the Institution on Friday, 24th October 1913, at Eight o'clock p.m.; Sir H. Frederick Donaldson, K.C.B., President, in the Chair.

The Minutes of the previous Meeting were read and confirmed.

The President said that, before the business of the evening was commenced, he trusted the members would allow him to express the hope that the Session now being entered upon would be eminently successful from every point of view. He was full of regret that the building operations were still incomplete; the Council, however, were in hopes that it would not be long before the last of the workmen could be dispensed with. The members were aware that it was proposed to hold a house-warming, but in view of the present condition of the staircase every one would, he was sure, agree that it could not take place just yet. It had been hoped that something of the sort might be held in November, but the Council, after discussing the matter at its meeting that afternoon, came to the conclusion that probably the best thing to do would be to make the house-warming an adjunct, if he might say so, of the first "Thomas Hawksley" Lecture, which would be delivered by Mr. Edward B. Ellington,

(The President.)

Past-President, on Friday, 5th December, at Eight o'clock, when it was hoped that ladies might find it convenient to come to the Institution at about Half-past Nine.

The members would remember that there had been a good deal of discussion in the past with regard to giving extended facilities to country members. A definite suggestion had emanated from Manchester that something should be done during the present Session, and the Council had agreed to hold a Meeting which would be an adjunct to the next Meeting to be held in London, that is, the same Paper would be read at Manchester on Thursday, 20th, and in London on Friday, 21st November, and be discussed at both places. One of the most important features of the Manchester Meeting was that the Council had invited any of the members who lived in that neighbourhood to meet them in an informal way at five o'clock, before the Ordinary Meeting was held, in order that they might hear what it was that the members in the Manchester district thought could be done more to their advantage than was done at the present time. Whether anything further would come out of that remained to be seen, because it was desirable to hear what the wants of those local members were, before the Council could say whether they were possible of realization.

Then there was another very important feature to which he desired to draw special attention. All the members had received notices with reference to the Benevolent Fund, a Meeting of which would be held at the close of the present Meeting. It was a Statutory Meeting which had to take place within a certain period of the registration of the Company, the Benevolent Fund having been converted into a Company under legal advice. At that Meeting the Officers and Committee would be elected for the ensuing year. He regretted to say that the invitation to contribute to that Fund by donations and annual subscriptions had not yet been taken up by the members so whole-heartedly as he could wish. A certain amount of support had been received. He wished to impress upon the notice of the members that every one of them —it did not matter whether they sat on the Council or the

Members' side of the table—was liable to have a bad time. It was their duty to their neighbour to accord all the help that lay within their power, and help those who, probably from no fault of their own, were in deep waters of financial affliction. Moreover, a man dying in harness and at a time when his finances were perhaps at their lowest should be able to feel that there were people with sympathies who had the command of a certain amount of money, which could be disbursed in the strictest confidence for the benefit of their beloved ones. He could not commend the Benevolent Fund to the members with too much warmth, and he earnestly asked them to support the Council in making it of real, good and lasting assistance to those mechanical engineers who might be in need. With regard to the Meeting that was to be held after the present Meeting, strictly speaking it was a meeting of Members, that is, those who had given in their adherence to the scheme by making either a donation or by promising annual subscriptions, but speaking not only for the Council but for the Managing Committee, over which he had the honour to preside at the present moment, he wished to announce that they would welcome all to hear the statement that would be made, and who would thus, he trusted, be interested in the object the Council had in view.

Another important announcement he had to make was that the first of the Examinations had taken place both for Graduates and for Associate Members, and he thought the Council had reason to be pleased with the results. Seventeen candidates sat for the two Examinations, and seven passed in each class, which was fairly hopeful for the future. He hoped the younger men present would let their friends know that the examination was not such an ordeal after all. He urged candidates not to hang back, but to come forward and pass the examination.

The President announced that the Ballot Lists for the election of new Members had been opened by a Committee appointed by the Council, and that the following fifty-nine candidates were found to be duly elected:—

MEMBERS.

Bond, Frederick Arthur,	London.
Capon, Clement Bernard,	Rotherham.
Grove, Edmund Philip,	Melbourne.
Hinde, George,	Buenos Aires.
Robinson, John Edmund,	Ipswich, Queensland.

ASSOCIATE MEMBERS.

Andrews-Vickery, Herbert,	Chudleigh, Devon.
Backhouse, Walter Sydney Ackroyd,	Cheadle.
Bargate, George, Jun.,	Newcastle-on-Tyne.
Bumpus, Frank Arnold,	East Pittsburgh.
Butcher, Alexander Cranston,	Fremantle, W.A.
Cable, Gordon Porter,	Bombay.
Cardew, David,	Moradabad.
Chapman, Horace William,	Leeds.
Cole, Donald Braithwaite,	London.
Crompton, Walter Ernest,	Wallsend-on-Tyne.
Cully, William Frederick,	Woolwich.
Dawson, Thomas,	Coventry.
Day, Frank Duval,	Gold Coast.
Doyle, Thomas Davis,	Melbourne.
Fewster, Ebenezer Drysdale,	Preston.
Garner, Harold Charles,	Manchester.
Goudie, Harry James,	London.
Greenland, Harold Francis Albert,	Luton.
Gush, Arthur Sydney, Engineer Lieut. R.N., ret.,	Southampton.
Hamilton, Benjamin Henry Noël Hans,	London.
Hartree, Raymond,	Saharanpore.
Hayes, Joseph John,	Manchester.
Holmes, Herbert,	London.
Jackson, George James,	St. Anne's-on-the-Sea.
Johnston, William Arthur,	Manchester.
Jones, Stanley Walter,	Auckland, N.Z.
Lindsay, William James,	Camden, N.J.

Lloyd, George Wilmot,	Antofagasta.
London, Arthur Geoffrey,	London.
McCormick, James,	Hull.
McCourt, Ernest Francis,	London.
Mackenzie, Robert Archibald,	Rangoon.
Maclean, Andrew Fraser,	London.
Main, Gordon Willmott,	Portsmouth.
Maynard, Percy Victor,	London.
Mitchell, James,	London.
Naylor, Thomas Liddle,	Guadix, Spain.
Nelson, Lionel,	Napier, N.Z.
Norton, Stephen James,	Ilford.
Phillips, George William,	York.
Powell, Henry,	Gainsborough.
Punter, Alfred,	Kuala Lumpur, F.M.S.
Roberts, Edward Fletcher,	London.
Smith, Francis Bede,	Hubli, India.
Tomlinson, John Arthur,	Saidpur, India.
Twelvetrees, Richard Walter Rickard,	London.
Walcroft, Thomas Clarence,	Calcutta.
Woodhams, Percy Payne,	Vancouver.
Wright, John Laird,	Mohammerah.

GRADUATES.

Anderson, Sydney Drummond,	Attleborough.
Bond, Frederick William,	Brighouse.
Issels, Henry Gordon,	Bulawayo.
Reid, Francis Heine,	Plymouth.
Santos, Antonio Victor dos,	Rio de Janeiro.

The President announced that the following twelve Transferences had been made by the Council:—

Associate Members to Members.

Back, Walter Herbert,	Great Yarmouth.
Brayshaw, Edmund Russell,	Manchester.

Burns, James Alexander, ...	Glasgow.
Clarke, Ashford Vincent, ...	Gainsborough.
Elliott, George Henry, ...	London.
Ford, Herbert Henry, ...	Glasgow.
Linnell, Arthur Evelyn, ...	Kettering.
Matthews, Thomas Leigh, ...	London.
Moffat, David, ...	Jujuy, Arg. Rep.
Pertwee, Herbert Arthur, . . .	Great Yarmouth.
Somers, Frank, ...	Birmingham.
Westley, Arthur William, . . .	East London, C.C.

The following Paper was read and discussed:—

"Modern Flour-Mill Machinery"; by Robert B. Creak, *Member*, of Manchester.

The Meeting terminated shortly before Ten o'clock. The attendance was 121 Members and 55 Visitors.

MODERN FLOUR-MILL MACHINERY.

By ROBERT B. CREAK, *Member*, of Manchester.

Since the date of the last Paper on this subject, read before this Institution by the late Mr. Henry Simon in 1889, considerable advance has been made in the art of Milling. The object of the present Paper is to bring together the leading developments since that date in wheat-preparing and roller-mill machinery. The modern tendency has been to locate mills on the waterside at the principal ports and to increase the capacity of the single plant, in each case with a view to economy in cost of production. To-day 50 sacks (each containing 280 lb. of flour) per hour may be taken as about the maximum output for a single plant.

A common practice is to arrange the mill building with two separate 50-sack plants placed back to back, Fig. 1 (pages 994–5), showing such an arrangement in cross-sectional elevation. The line of elevators is seen down the centre with the two plants on either side. The building has five floors. No. 1 floor contains the line shafts driving the roller-mills, and the elevator boots. No. 2 floor carries the roller-mills in six lines. Nos. 3 and 4 floors contain lines

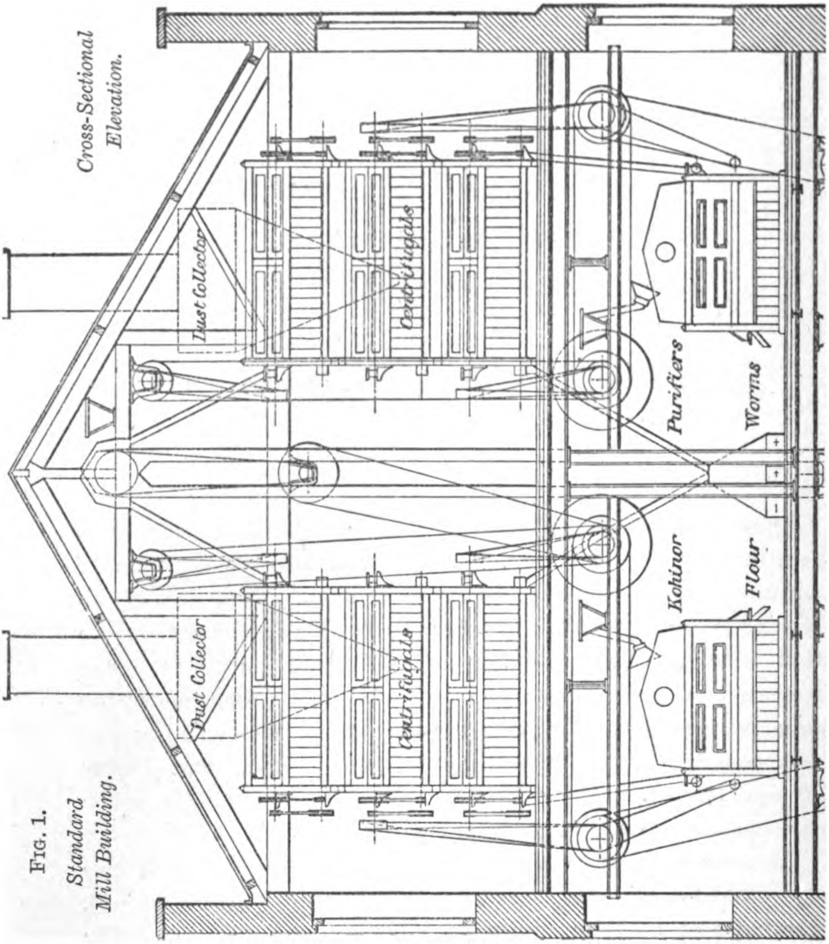
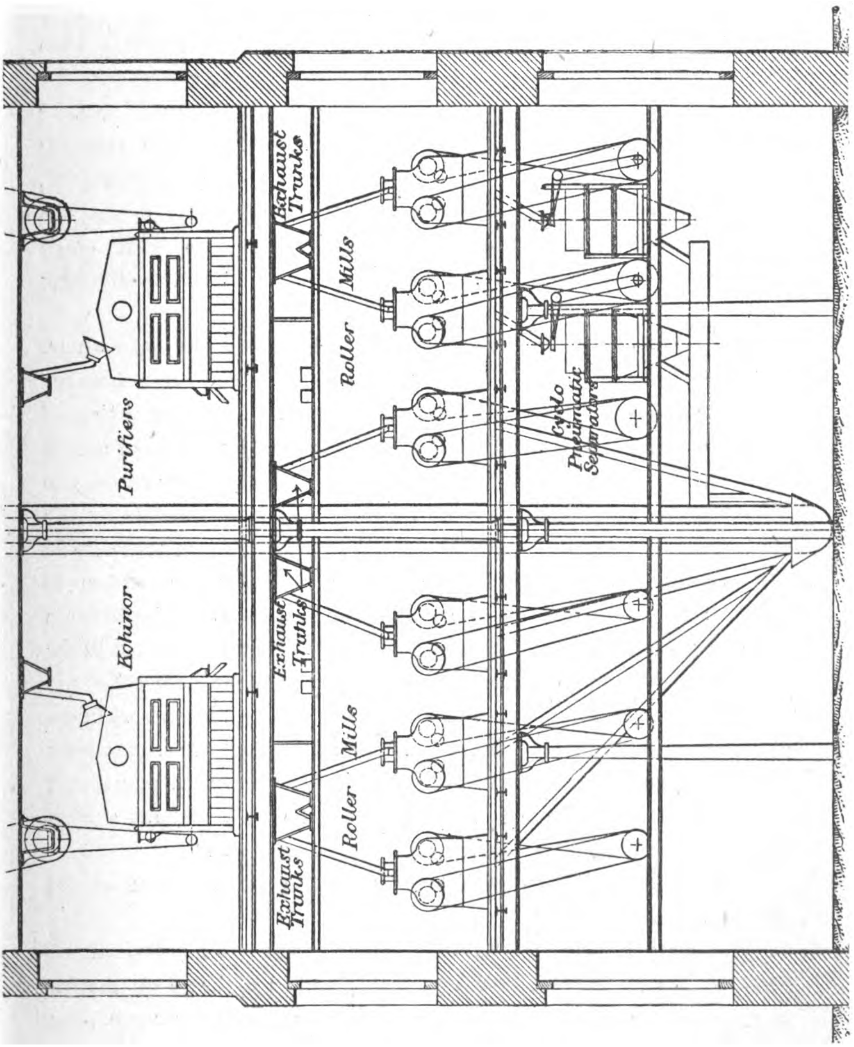


FIG. 1. *Standard Mill Building.*

Cross-Sectional Elevation.

(Continued below.)



(Continued from above.)

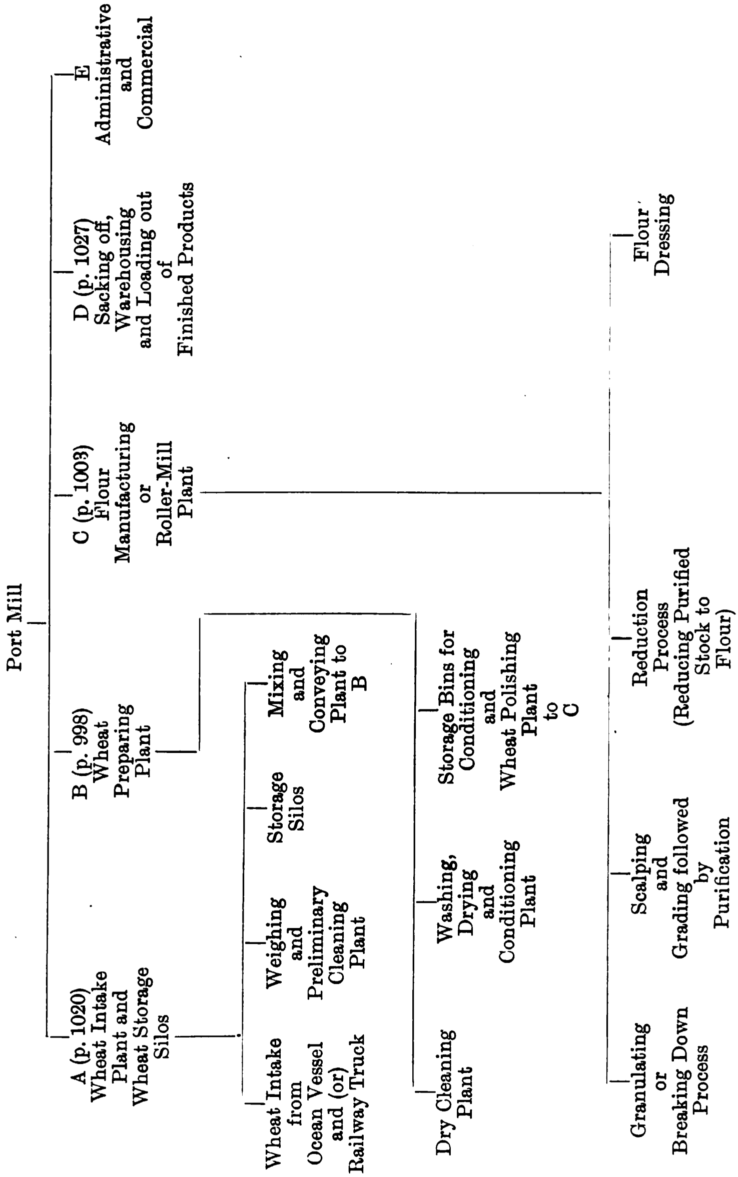
of purifiers. No. 5 floor contains the centrifugal dressing machines in two rows, the machines being piled three high. The elevator heads run up nearly to the roof ridge.

Such a building, designed to contain two 50-sack plants with suitable wheat-preparing plants at the far end, and a rope-race for main drives separating the two sections, would consist of, say, 30 bays 8 feet span. Frequently, for the sake of greater security from fire, and with a view to lowering the fire insurance premium, the two plants are divided by a longitudinal wall down the centre of the cross-sectional view, in which case each plant would have its own line of elevators placed close along this dividing wall.

In considering the above arrangement and the subsequent detailed descriptions of machines, it is necessary to remember that the milling process is entirely automatic. From the lifting of the wheat from the hold of the importing vessel by means of a ship elevator, to the delivery of the finished products into the sacks, the wheat grains and the various mill stocks are never touched by the operative, as they gravitate by spout from machine to machine in the process and in their course are elevated from the bottom to the top many times, and are conveyed horizontally considerable distances before completing their journey. From this it will be noted that the disposition of the machines on the various floors is a matter of great importance, and requires considerable skill to avoid needless travel of the stocks. From the foregoing, it follows that comparatively little attention is required to run the plant, and in consequence all large mills run day and night, without a stop for meals, from Monday morning till Saturday night.

The up-to-date port mill admits of the classification of its processes shown on page 997.

The author proposes to deal first with Sections B and C. Sections A and D, which involve the handling of large quantities of grain in bulk and sacks of finished products, moving these long distances horizontally and vertically, are dealt with on pages 1020–31. Group E, although of the highest importance, does not rightly come into the range of this Paper.


Port Mill
A (p. 1020)
Wheat Intake
Plant and
Wheat Storage
Silos
Wheat Intake
from
Ocean Vessel
and (or)
Railway Truck
Weighing
and
Preliminary
Cleaning
Plant
Storage
Silos
Mixing
and
Conveying
Plant to
B
B (p. 998)
Wheat
Preparing
Plant
Dry Cleaning
Plant
Washing,
Drying
and
Conditioning
Plant
Storage Bins for
Conditioning
and
Wheat Polishing
Plant
to
C
C (p. 1003)
Flour
Manufacturing
or
Roller-Mill
Plant
Granulating
or
Breaking Down
Process
Scalping
and
Grading followed
by
Purification
Reduction
Process
(Reducing Purified
Stock to
Flour)
Flour
Dressing
D (p. 1027)
Sacking off,
Warehousing
and Loading out
of
Finished Products
E
Administrative
and
Commercial

The author will now proceed to describe the newer machines employed in groups B and C. To appreciate their points, it must be borne in mind that the ideal of the wheat-preparing plant is to pass clean and sound wheat grains only to the roller-mill plant, and these in the most suitable condition for milling; and that of the roller-mill plant to remove the skin of the wheat berry in as large pieces as possible, leaving the kernel entirely free from adhering particles of this skin, whilst at the same time leaving no floury particles on the skin. The skinned kernel could then be reduced to fine white flour by the reduction rolls. Needless to say, the long series of machines comprising a modern roller-mill plant only approximately fulfils these ideal functions. It must also be borne in mind that the British miller has the choice of all the wheats of the world, which differ widely from each other in characteristics such as colour, size, hardness, freedom from impurities, etc., and one of his most difficult tasks is to select those wheats which, when treated on the wheat-preparing plant and afterwards mixed together in suitable proportions, shall give the required yields of the standard grades of flour, and at the same time yield a profit on the cost of the mixture.

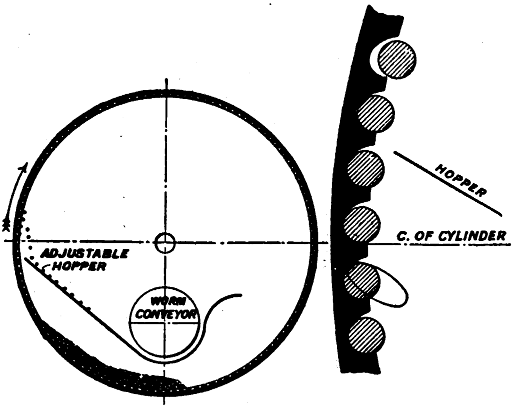
A large port mill will seldom have less than three separate wheat-preparing plants running simultaneously and treating the different wheats grouped into three classes termed "hard," "medium" and "soft." Each group would receive its appropriate treatment. For instance, hard wheats would be washed twice to soften them; soft wheats perhaps not washed at all, or immersed in water for a very short time only; and so forth.

Wheat-Preparing Plant (Section B on page 997).—The dry cleaning processes consist generally of riddling for the removal of impurities larger and smaller than the wheat berries, of severe rubbing action, termed scouring, for loosening dirt adhering to the skin of the grain, of subjecting the grain to the action of brushes with stiff bristles, and at all points subjecting the grain to the action of wind currents to carry off the loosened light floating dust.

Most wheats contain other seeds as impurities. Those seeds larger or smaller than the wheat berries can be easily separated by riddling. There are grains, such as the cockle seed, a small round black seed, barley and oats, whose girth is the same as the wheat berries. Obviously riddling is here ineffective, and use is made of a difference in shape to make the separation.

Cylinders slowly revolving on slightly inclined axes are constructed of plates pitted on the interior with indentations, Fig. 2. The grain to be treated is fed in at the upper end, and travels slowly down the inside of the cylinder. In the case of cylinders with small pits, the small round cockle seeds rest in and are lifted by the pits on the rising side of the cylinder. It will be clear that the wheat berries will roll out of the pits at a lower level than will the cockle seeds. If now an adjustable hopper or tray is fitted the full length of the inside of the cylinder, arranged so that its lip or edge lies almost touching the inner surface of the rising side of the cylinder, and if this edge be set at the right level it will catch the falling cockle seeds, whilst the wheat berries will roll out of the pits into the body of the cylinder before the lip of the tray is reached. This action is illustrated in Fig. 2. With cylinders having large pits, the wheat berries are lifted higher than the barley or oats which, with the bearded end, are longer than the wheat berries.

Fig. 2.—*Cockle Cylinder, Cross Section.*



This method is quite effective, but suffers from two drawbacks. The wear on the inner pitted surface is rapid, and only a comparatively small surface of pits is in use at one instant. To meet these objections, a new type of machine has been evolved, illustrated in Figs. 3 and 4. The essentials of this machine are the travelling band AA set in a frame at an inclination to the horizontal. This band is composed of plates pitted with small holes to contain and hold the round cockle seeds. As the band travels upwards, the frame in which it is carried is given a short-stroke, but rapid, cross shake. The wheat, intermixed with the cockle

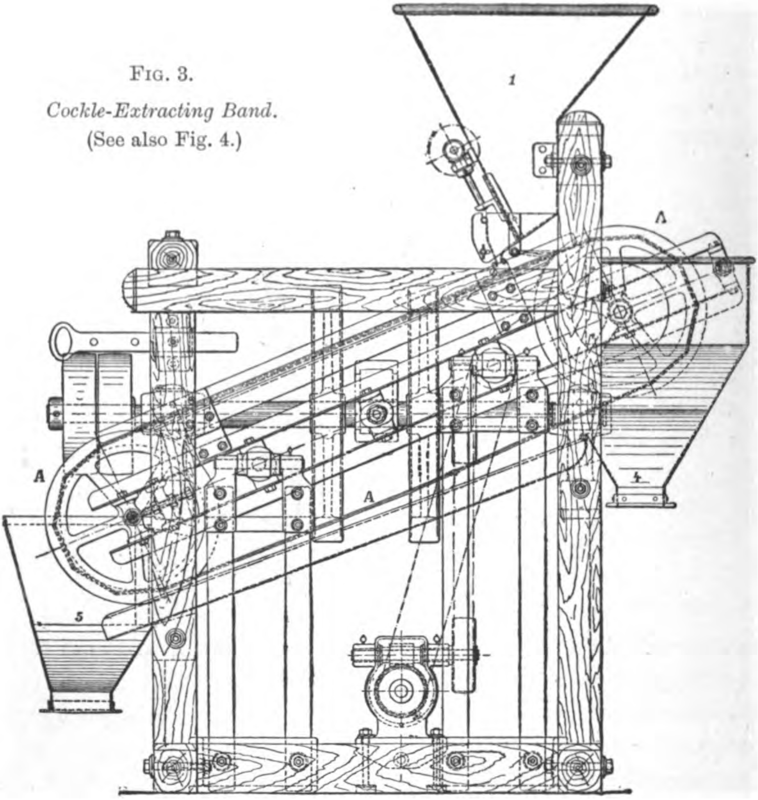


Fig. 3.
Cockle-Extracting Band.
(See also Fig. 4.)

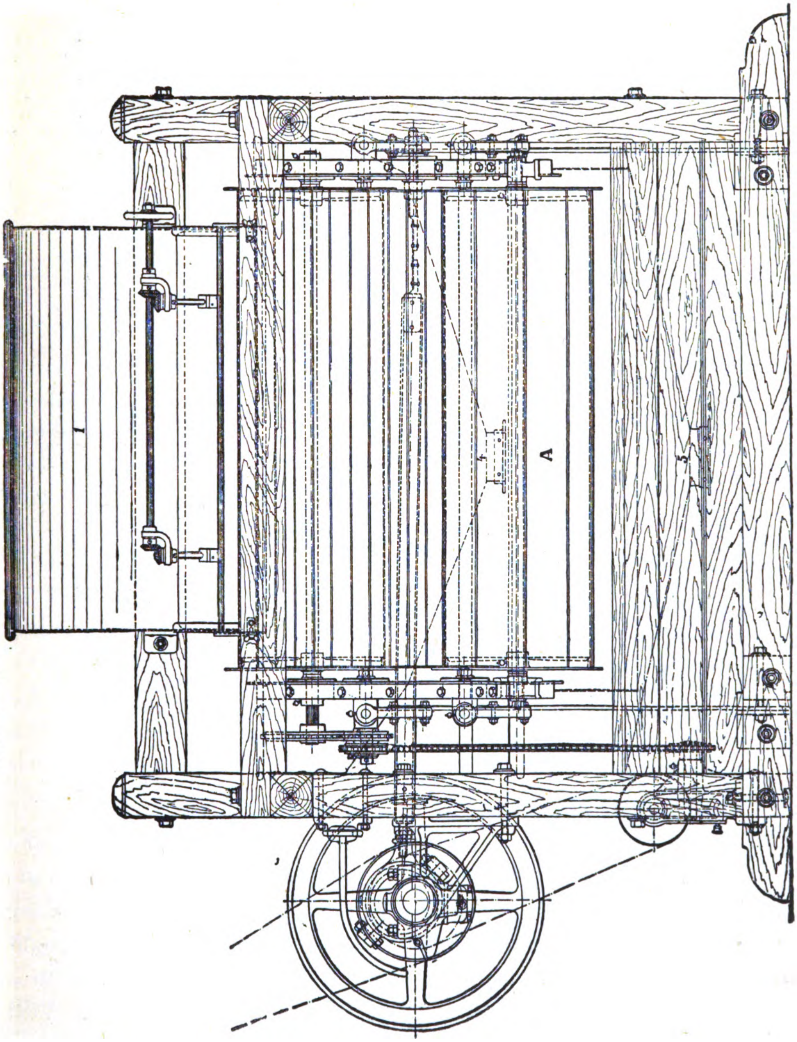
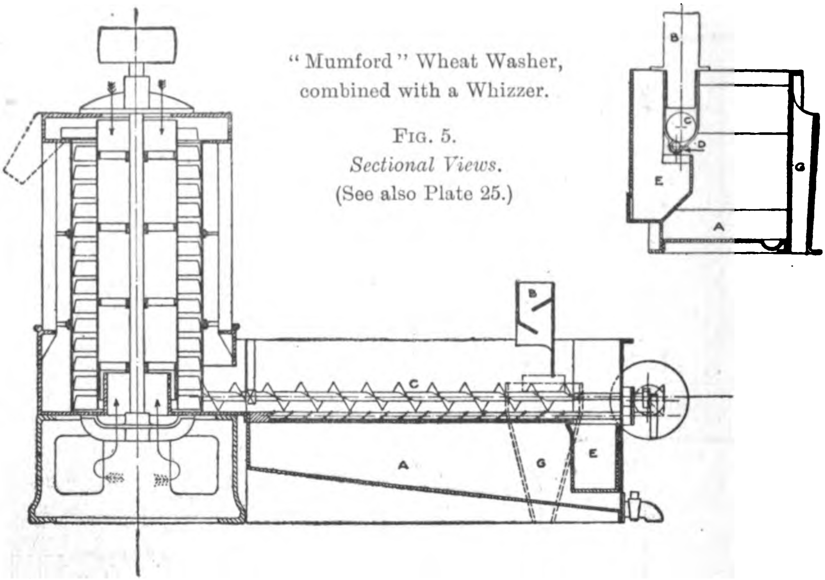


Fig. 4.—*Cockle-Extracting Band.* (See also Fig. 3.)

seeds, is fed in at hopper 1 placed at the highest part of the band, and the angle of inclination is such that, with the agitation caused by the cross shake, the wheat grains roll down the band and are collected in receptacle 5, while the cockle seeds remain in the pits and are carried over the head of the band and dropped into the box marked 4. It is claimed that this device makes a closer separation and utilizes more of the pitted surface.



"Mumford" Wheat Washer, combined with a Whizzer.

FIG. 5.
Sectional Views.
(See also Plate 25.)

Wheat Washing.—The washing of wheat has become general in all British mills. It serves the twofold purpose of a cleanser and at the same time a softener of the harder varieties. For wheats containing stones, washing affords the surest means of separating these. The "Mumford" wheat washer and stoner recently brought out is illustrated on Fig. 5 and Fig. 6, Plate 25, combined with a whizzer or centrifugal dryer. The washer consists of tank A filled with water up to a level about 2 inches below the top of the washing worm C. Immediately below the washing worm is the stone-removing worm D. Wheat is fed on to the washing worm through the feed-box B. This box can be moved along the length of washing worm C to accommodate tender wheats requiring a very short immersion. The revolving of the washing worm imparts a pulsating motion to the water, which keeps the wheat floating on the surface, whilst the stones, which are a little heavier than the wheat grains, sink and are caught by the small stoning worm D and conveyed to and deposited in box E. The wheat floating on the surface of the water is carried along by the worm and by the flow of water along the worm trough into the whizzer, whose function is to throw off surplus moisture by the usual centrifugal action. Fresh water is constantly running into the tank whilst the water thrown off by the whizzer drains back into the tank, a constant level being maintained by the overflow head at G.

In other forms of wheat washers, use is made of a plunger to produce the pulsation, or the effect simply of gravity is relied upon to sink the stones, but in all cases the wheat is borne along by a stream of water flowing from head to tail of the machine over a weir.

¶ *Flour Manufacturing or Roller-Mill Plant* (Section C on page 997).—The roller-mill is used for two distinct purposes. In the earlier stages of the process it is fitted with fluted rolls of varying coarseness for breaking down the wheat berry, the upper and lower rolls of each pair being driven at different rates of revolution in the ratio of about 2½ to 1 by means of machine-cut gear-wheels. In the later stages of the milling process, smooth rolls with a difference in revolution of about 1½ to 1 are used for reducing the purified semolina and middlings to flour.

The standard roller-mill as made in this country is the 4-roller mill, that is, one frame containing two pairs of rolls. These are placed with their axes in a plane inclined to the vertical. Up to comparatively recent times there was no uniformity in this matter. Some makers placed all four rolls in a horizontal plane, whilst others placed each pair in practically a vertical plane.*

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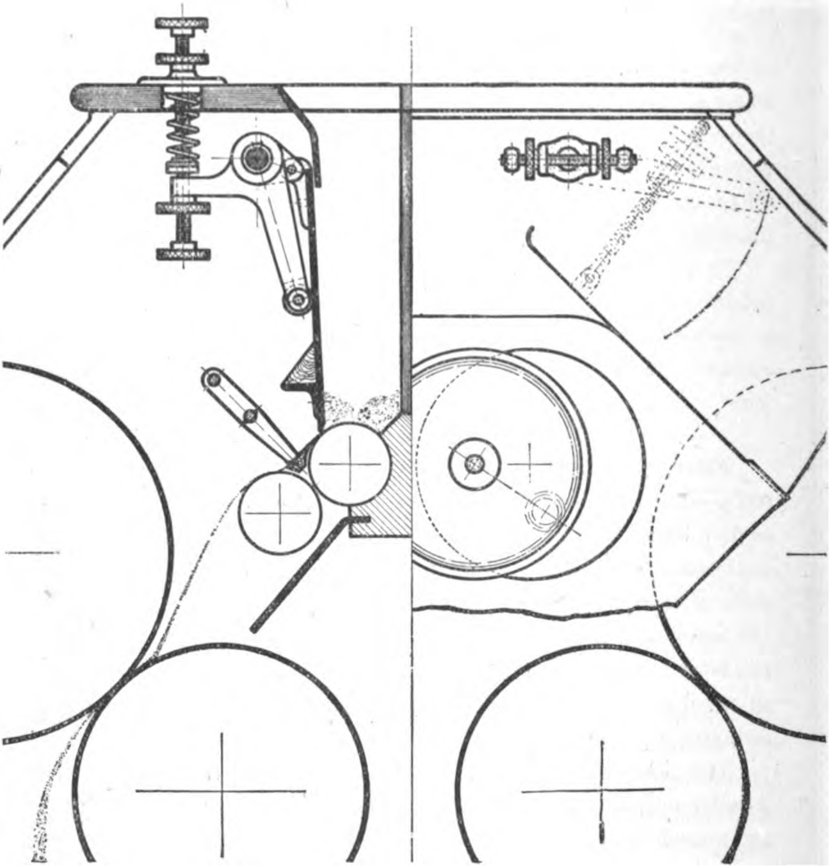
* *See* Paper by the late Mr. H. Simon, Proc. I.Mech.E., 1889, page 148.

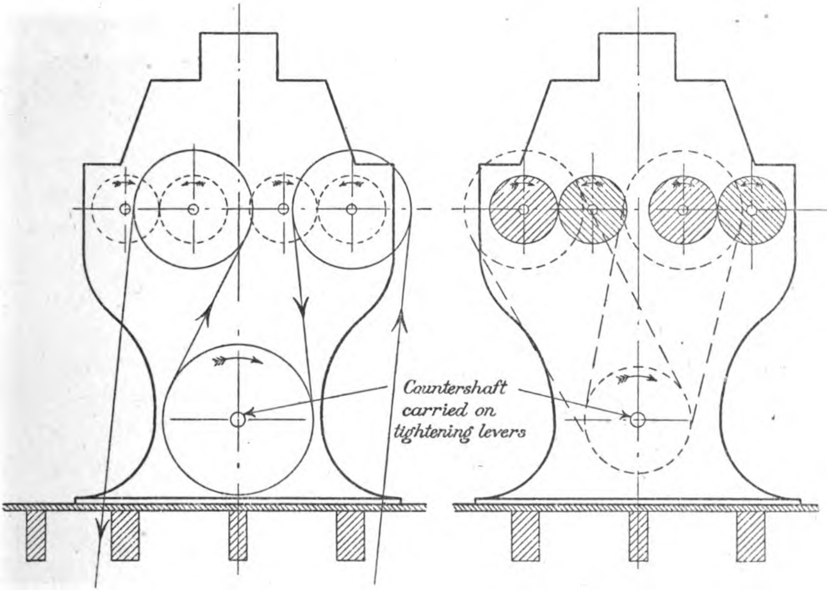
Now the diagonal arrangement has become universal. Doubtless it is a compromise to secure the advantages of both the above arrangements. With the four rolls in the same horizontal plane an unduly wide machine is formed, which would prevent placing three lines of rolls with adequate passage ways in a mill building of normal width; this is a point of importance as affecting economy of space. Fig. 7 shows in cross-sectional elevation the diagonal

FIG. 7.—*Four-Roller Mill.*
(Cross-Section showing diagonal arrangement of the Rolls.)



placing of the rolls. It will be noticed that the upper rolls are of larger diameter than the lower. When this is the case, the rolls are fitted with equal gear-wheels, the difference in diameter of the rolls giving the necessary differential in peripheral speed. The more usual practice is to use rolls of 10 inches diameter throughout with the differential gears.

Fig. 8.—*Four-Roller Mill.*
(Standard type as used in the United States and Canada.)



In the United States and Canada the type of roller-mill used is outlined in Fig. 8. The cast-iron body may best be described as the " hobble skirt " frame. The differential is obtained by belt drive from a countershaft running through the lower part of the frame. This countershaft acts as a tightening jockey-pulley to the single driving belt operating the two quick rolls. The two pulleys on the opposite end of this countershaft drive the two slow rolls. There are variations of this drive given in the American catalogues, but they all show the differential obtained by belts and not by gears. All four rolls are ranged in a horizontal plane.

Then, too, in the matter of speed the practice in the two countries differs. Here the majority of rolls are 10 inches diameter and the speed of the fast roll of each pair when breaking down is 350 revolutions, whilst for smooth roll reductions the speed for the fast roll is 210–220. American practice is to run the fast rolls at 500 revolutions per minute, whether on breaks or reductions. In English mills it is usual to run with thinner feeds, so that, on account of this and the lower speed of running, an English mill has a longer roller surface than has the American mill of equal capacity. There is a tendency here to increase the speed of the roller-mills though not to equal the American speeds. This would hardly be permissible with gear-wheel differential.

The author believes that no exhaustive tests have been made as to variations of differential, nor can he gather any information as to how the generally accepted differentials of to-day were determined. Very probably they have been handed on as an accepted tradition, and this might well prove a fruitful subject for experimental test.

The breaking down of the wheat berry is usually accomplished in four stages, with fluted rolls of varying coarseness; twelve flutes to the inch would be used for the first break, while twenty-eight to thirty flutes to the inch for the fourth break. The reason for breaking down in successive stages is to avoid, as far as possible, the production of flour during this part of the process, as it is of poor quality and is apt to be discoloured by contact with the bran. It is therefore desirable to isolate this break flour as soon as possible. Attention has of late been concentrated on this point. Until recently it was usual to leave this break flour in contact with the general break product, passing it all forward by elevator to the scalper. The scalping process has for its object the separation of the good semolina and middlings from the break flour on the one hand, and from the wheat still unbroken on the other. In the early days of roller milling, scalping was performed by centrifugal machines of the type illustrated on Fig. 9.* Scalping by centrifugal machines was a violent process. The machine consists of a slowly revolving barrel about 2 feet 6 inches diameter by 10 feet long, covered with wire or silk mesh as the case may require. Inside the barrel are fingered beaters, shown in the illustration, which revolve at 200 revolutions per minute inside the barrel. The stock from the break roll is fed into the barrel at each end, and is picked up by the beaters and thrown against the mesh covering the barrel. The finer stock is driven through the mesh and gathered in the hopper of the frame enclosing the barrel, whilst the large stock comes over the tail and passes to the next break. The author has described this machine at some length, as he will have to refer to it again when considering flour dressers.

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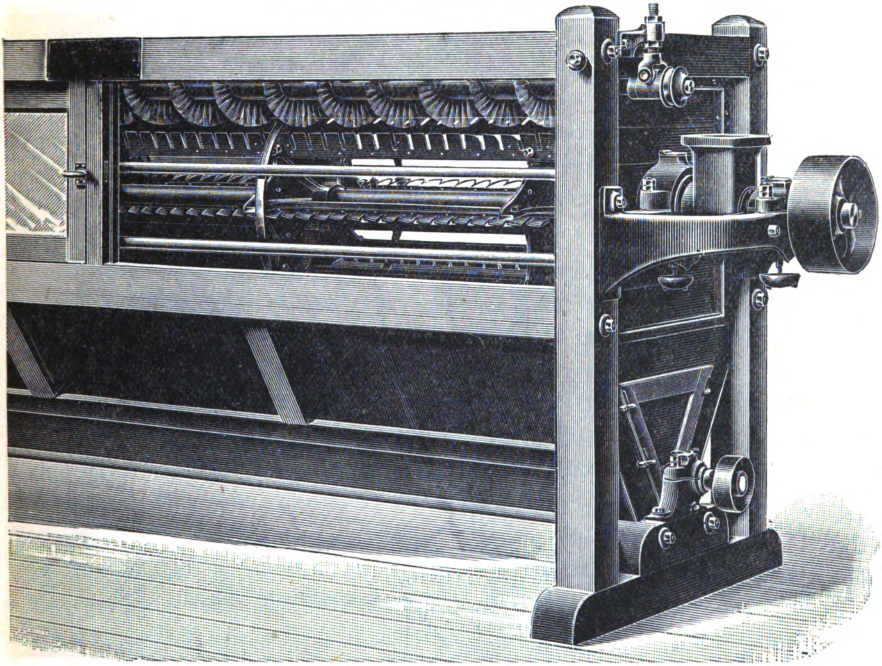
* *See* Proceedings, I.Mech.E., 1889, page 148.

Fig. 9.—*Centrifugal Dressing Machine.*
(Interior with one door removed.)



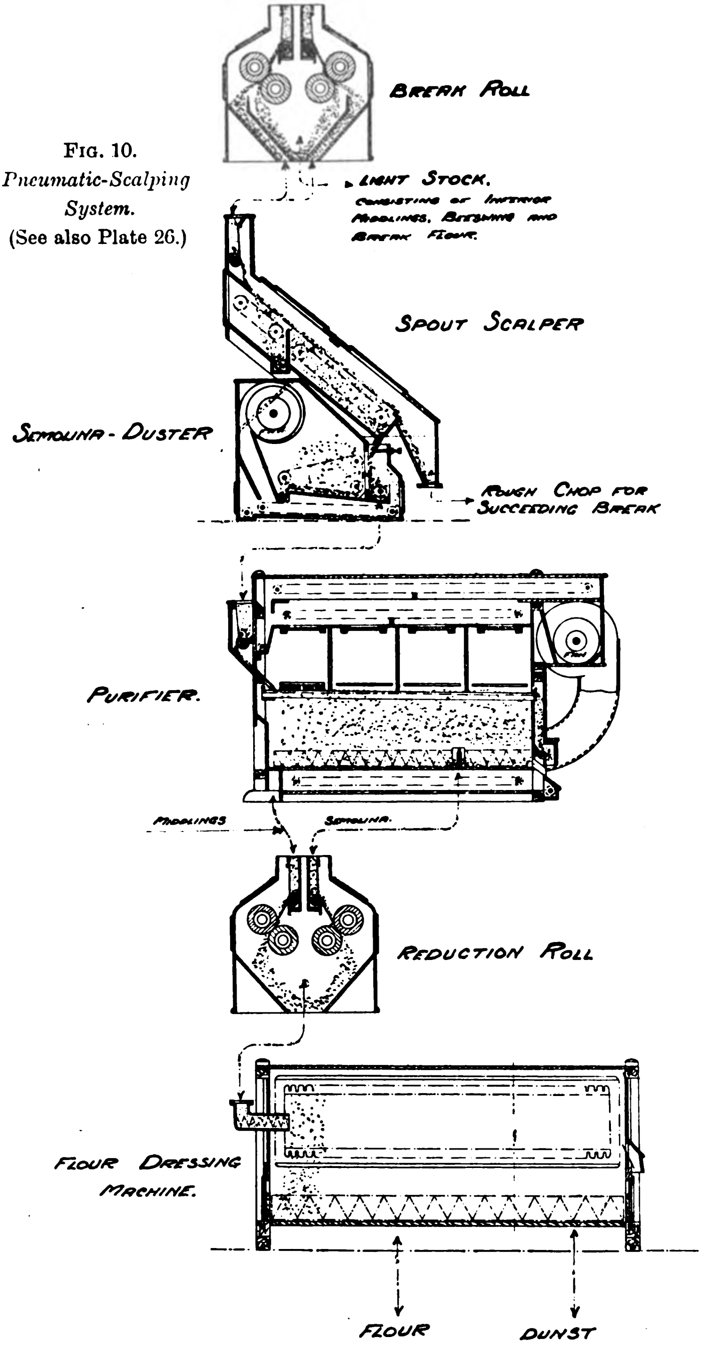


Fig. 10.
Pneumatic-Scalping System.
(See also Plate 26.)

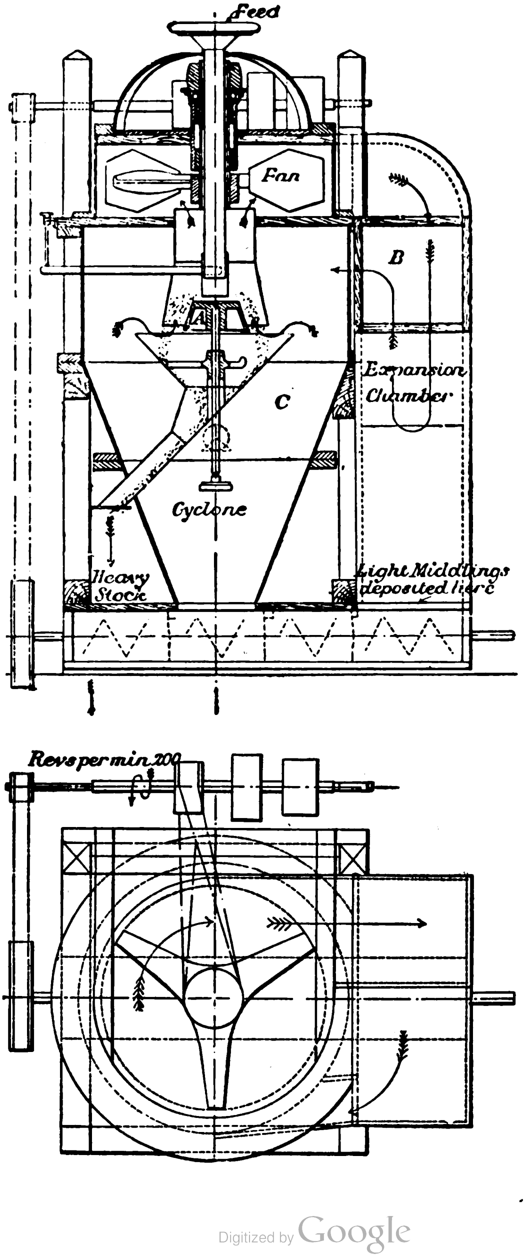
For a considerable time milling engineers have been devising gentler processes of scalping, with the object of isolating the break flour as soon as made, thus avoiding discolouration by contact with the bran, and avoiding the making of more break flour by attrition due to rough treatment in the process. Hence the use of wind currents, as part of the scalping process, has become very general.

Pneumatic-scalping in its simplest form is illustrated on Fig. 10. The break roller-mills are provided with double hoppers. The inner hopper is subjected to a light suction from a fan. As a result, the stock coming from the nip of the rolls is divided, the lighter inferior middlings with the break flour and light branny particles or bees-wing fall short, and are drawn into the inner hopper, whilst the high-class heavy semolina and the wheat particles carry farther against the air suction, and fall into the outer hopper. This separating action can be relied on without the use of any air suction at all applied to the inner hopper, but a light suction makes the separation more certain. Fig. 11, Plate 26, shows clearly the separating action on the stock coming from the nip of the roll as the result of gravity aided by a light suction. The high-class semolina and broken wheat would then be elevated and fed on to the spout-scalper, shown in general view on Fig. 12, and in section on Fig. 10. This machine is nothing more than an inclined sieve with hopper and feed roll at the top to spread the feed evenly across the sieve. The sieve is clothed with a suitable wire-mesh which tails over the broken wheat to the succeeding break, whilst the semolina passes through the mesh as the stock rolls down over the wire-cover. The collecting tray receiving the semolina passes its product on to the front of a vertical silk-covered screen. Whilst falling in front of this screen, the product is subjected to a continuously circulating air-current or air-belt which removes all light impurities. From the semolina scalper and duster the stock is ready for the purifier.

Fig. 13 (page 1010) illustrates a cyclo-pneumatic separator for the treatment of break stock immediately after leaving the break roll. This machine is arranged on the enclosed continuous air-current or air-belt principle. The stock from the rolls passes

Fig. 13.

Cyclo-Pneumatic Separator.



down the central feed pipe at the top of the machine on to the revolving plate A, by which it is spread, and forms an annular stream of stock falling evenly all round into the fixed hopper immediately below. The revolving feed-plate is enclosed by a sheet-iron hood leading up to the eye of the fan. This fan causes the air to circulate in the direction of the arrow heads. It will be seen that the stock falling all round the plate is subjected to the circulating air-current which carries up into and through the fan the light materials, such as, break flour, light branny particles termed "bees-wing," and the light inferior middlings, leaving the heavy semolina along with the wheat particles requiring further granulation to pass out together to be afterwards separated on another machine. The air current from the fan passes to the expansion chamber B, in which are deposited the lighter middlings, whilst the flour is deposited in the cyclone C. The separations are made entirely on the air-belt system, no outside air being required, thus preventing flour discolouration due to soot flakes, but on the other hand the stock from the break rolls has to travel to this machine before the break flour is separated from it. Whenever possible the cyclo-pneumatic separator is placed directly below the break roll it is to follow.

No very sweeping changes have been made in the construction and arrangement of purifiers. There is a decided movement back to the old-fashioned plan of coupling the line of purifiers to one common exhaust trunk with independent fan at the end coupled to a textile dust-collector. This system is largely replacing the so-called dustless purifier with slow running fan fitted to each purifier, and an elaborate system of dust traps and settling chambers, provided in the upper part of the machine. The fans eventually discharged into the open purifier floor. It was found, however, that this arrangement, however carefully planned, passed some fine dust out into the mill floor. The common exhaust-trunk has been made possible by the improvements that have been effected in textile dust-collectors and the relaxing of the high charges which used to be made on such collectors when placed in the mill. It has the advantage of doing away with the settling chambers in the purifier, which serve to retain dust in the corners, to the delight of the moths, and also obstruct the light and the free examination of the sieve surface.

Fig. 14, Plate 27, and Figs. 15 and 16 show very clearly how the space above the sieves can be arranged to give a clear view of the working in a purifier arranged to couple up to a common exhaust trunk, and therefore without a fan in the machine itself.

FIG. 15.—*Purifier without Fan.* (*See also Fig.* 16.)

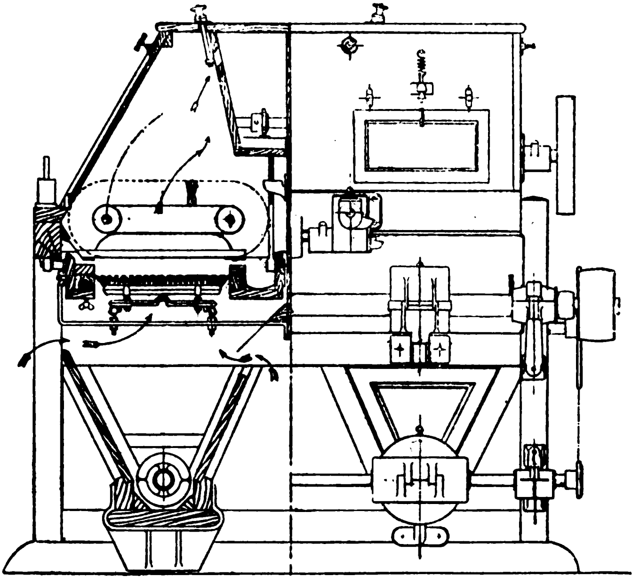


Fig. 17, Plate 28, shows a purifier self-contained with its own fan and a closed air-belt or circuit. This avoids the defect of putting out any dust into the mill floor, and avoids the necessity of using the large common air-trunk and textile dust-collector. It must, however, retain the settling chambers and the fan in the upper part of the machine, making the sieve not so easily visible.

In regard to the question of dressing out the flour after the purified semolina and middlings have been through one or more pairs of smooth rolls, it is perhaps here that the sharpest cleavage

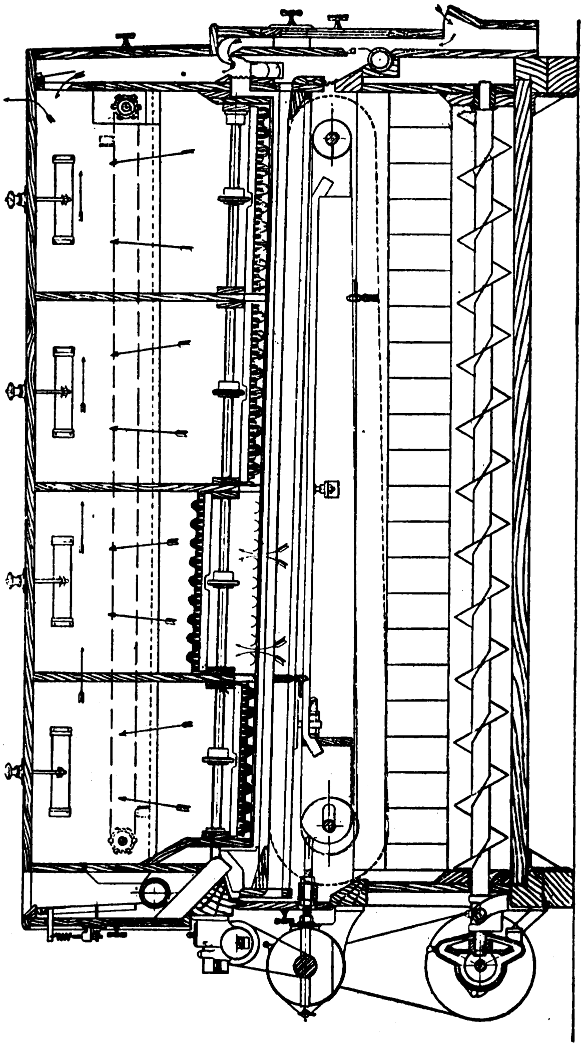
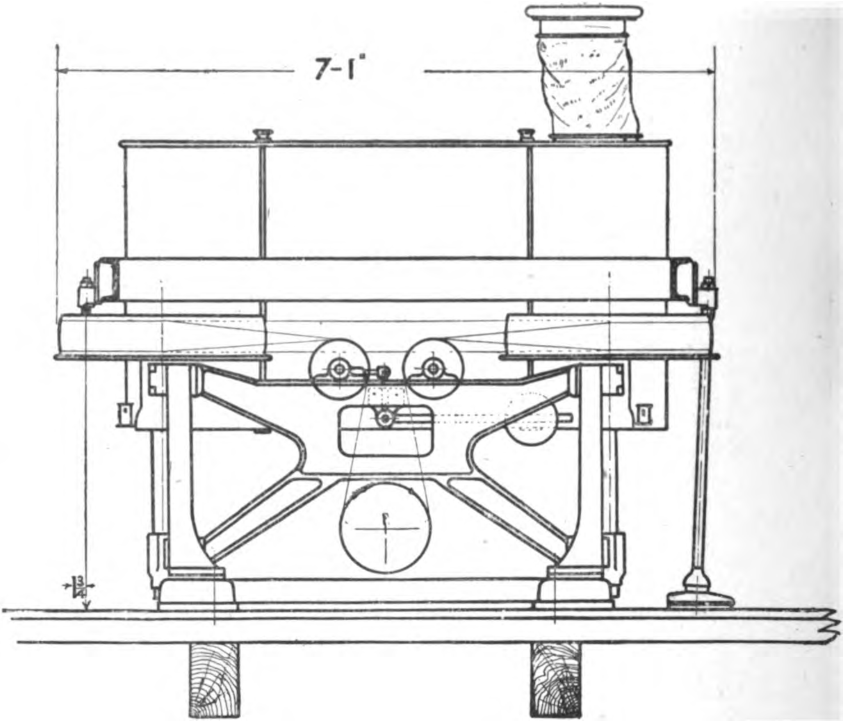


Fig. 16.

Purifier without Fan. (See also Fig. 15.)

of milling opinion occurs. Until recently, flour dressing in this country has always been considered as the work of centrifugals.* But to-day there are practical millers who consider the plansifter

Fig. 19.—*Double-Crank Plansifter.*



a satisfactory machine for this work. Before discussing this question, the author will consider the plansifter and its arrangements.

The plansifter originated in Hungary, the mother country of the roller-milling system. It was introduced into this country some twenty years ago, but, in this early stage of development, it was not successful. Since then it has made marked headway on

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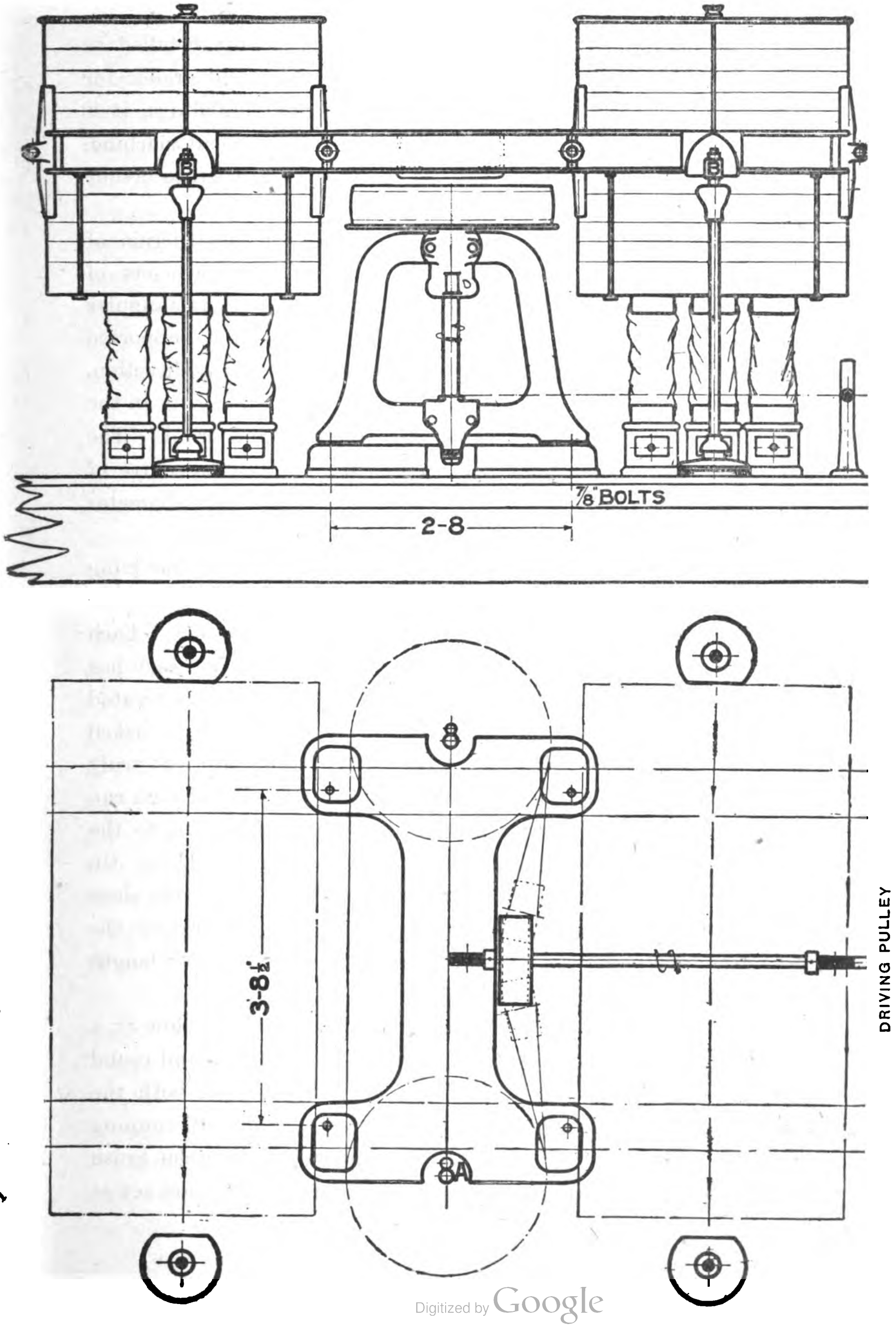
* *See* Proceedings, I.Mech.E., 1889, page 148.

Figs. 20 and 21.—*Double-Crank Plansifter.*



the Continent, and especially in Germany, and is now installed in several English mills. Used simply as a scalper and grader for treating break stock and preparing semolina and middlings, it is very generally admitted by millers here to be an excellent machine, but it is as a flour dresser that it has yet to win its way into favour with the British miller.

Fig. 18, Plate 29, and Figs. 19–21 illustrate the construction of the plansifter. The machine consists essentially of two sets of superimposed sieves, usually twelve deep carried in a rectangular frame. This frame is either suspended from above or supported from the floor by four upright rods free to swing in any direction. The frame is set level, and a rotary motion is imparted to it in the horizontal plane by means of a vertical spindle and crank. The crank measures about 1¾ inches from centre of shaft to centre of pin, so that the frame swings in a circular path having a diameter of 3½ inches, and makes about 180 revolutions per minute.

The set of superimposed sieves at each end of the frame lying twelve deep are each divided into two compartments, making four separate sections capable of treating four different stocks. Each sieve is suitably clothed with silk or wire as required, and each has a tray between it and the sieve below. The stocks to be treated are fed in at one end of the topmost sieves. It will be asked how the material travels along the silk, if they are set truly horizontal. This is accomplished by fixing to one side of each run small tin projecting pieces, standing out at right angles to the sieve side, and almost touching the silk surface. These tin projections form stalls or pockets ranged along the side of the sieve run. The oscillatory motion imparted to the sieve throws the stock from one pocket to the next, and so on down the full length of the sieve until it arrives at the tail end.

Between the underside of one sieve and the tray below it, a travelling brush is made to pass down one half width, and round and up the other half width. The brush is bristled on both the top and bottom sides. It is guided by a slotted guide-rail running down the centre of each sieve run; the connection between brush and slot is by a ferrule working on a pin. The bristles are set at an angle to cause the brush to travel in a definite direction. The bristles on the top side brush the underneath of the silk above, and those on the underside brush up the throughs, which have rained down on to the tray through the meshes of the silk, and they pass down as the feed to the next sieve below. All these details are very carefully worked out, and in practice are found not to give trouble. The crank or cranks actuating the plansifters carry balance-weights carefully adjusted, and quite a common test is to run the plansifter with the holding-down bolts removed to show the perfection of balance attained. In Fig. 22, Plate 30, is shown the single-crank arrangement.

Amongst the claims put forward for the plansifter as against the centrifugal mill are: saving in power; saving in space; saving in wear and tear of silk; gentle treatment of stocks; reduced amount of elevating and conveying consequent on the arrangement of superimposed sieves; and less obstruction to light consequent on reduced height. On the other hand, those who oppose, urge the accessibility of the centrifugal and ease of temporary repair in the event of the silk being holed; and accessibility of silk surface for brushing.

Undoubtedly the plansifter has found great favour in Germany. It is a very interesting machine from a mechanical point of view. It utilizes the whole of the silk surface at one time, which is not the case with the centrifugal. Fashion or custom and familiarity are powerful factors affecting choice of machines, and further, simplicity of action and ease of accessibility in a night and day automatic process are highly esteemed. It is urged by some that the plansifter will not dress through fine silk numbers in our damp climate. The author has seen some remarkable dressing through No. 17 silk, which is a fine number even for a centrifugal. As against this, the claim so often made that the plansifter is gentler in action than the centrifugal is one that is open to question. When one thinks of the stock being pitched forward from compartment to compartment, one must admit that there is some rather rough treatment in this process. It is the balancing of these fine points that gives rise to the difference of opinion as to the merits of this machine.

Textile Dust-Collector.—This apparatus, Fig. 24, Plate 31, is coming into very general use, and is frequently placed on the suction side of the fan. As shown in Fig. 23, Plate 30, it consists of a number of vertical tubes of textile material about 8 inches diameter and about 14 feet long. These are arranged in groups of eight to a compartment. The lower ends of the tubes are attached by flexible connections to spigots in a tube-plate, forming the top of a hopper, whilst the upper ends are blocked. The suction-pipe leads into the bottom hopper. Each set of eight tubes is enclosed in an air-tight compartment opening at the top into a head piece or nozzle connected to the main air-pipe leading to the suction eye of the fan. In the nozzle there is a flap acting as a two-way valve. Normally the flap-valve leaves the connection from the compartment to the suction-pipe to fan through the nozzle open. In this position the dust-laden air, entering the hopper at the bottom, passes into the interior of the sleeves, and strains through the texture to reach the nozzle leading to the upper suction-pipe. In straining through the texture of the sleeves, the dust is left adhering to the inner surface. To remove this dust, the sleeves are intermittently shaken by means of tappet gear. Whilst a set of sleeves is being shaken, the flap-valve in the nozzle on top is thrown over, admitting air from outside into the compartment and at the same time closing the connection between that particular compartment and the top suction-pipe. As a consequence, the suction in the lower hopper draws in fresh air from the room through the tubes of that particular compartment from outside at the same time as the tubes are being shaken. By this combined shaking action and reversal of air current, the dust deposited on the inner surface of the tubes is loosened and drops into the collecting hopper at the bottom. The reversal of the current plays a very important part in the automatic clearing of the tubes, which again is vital in a process making separations by means of finely regulated air currents.

Motive Power.—The choice of motive power is governed by two principal considerations. It is the usual practice to run the mill

144 hours per week, as the milling process, being automatic, requires so little manual attention. The load is constant, as all the machines must run together to form an automatic plant. It is possible to stop the wheat-preparing plant for an hour or so, if there be enough wheat in hand to keep the roller-mill plant running, but the rule is to run the wheat-preparing and roller-mill plants continuously and together, the only stopping time being Sunday. Such a load is an excellent one for economical steam-driving with rope drives from fly-wheel to the several line-shafts on the different floors.

In the standard mill-building, the engine-house is placed at the back of the main building with the rope race dividing the wheat-preparing section from the roller-mill section.

These same conditions are also very attractive to the Electric Power Corporation, as providing a market for their power during the slack period between midnight and 6 a.m.

Electric driving is making some headway, but it can be demonstrated that current must be supplied at something like 0·4*d.* per B.T.U. before electric power can compete in price with steam. There is no field for individual driving, as the machines must start and stop and run together as a complete plant. The usual plan where electric driving is adopted is to put down a motor for driving the wheat-preparing plant, one for driving the roller-shafts on the bottom floor, and one for driving the upstairs line-shafting. There are about a dozen flour-mills driven by electric power at present in this country, and these report very favourably on the system. Greater regularity of speed is one of the claims made for electric driving. This is a matter of very great importance where so many separations are effected by the use of delicately adjusted air-currents. Variations in line-shaft speed become greatly exaggerated when dealing with fans driven from them at high speeds. A considerable saving in space is made by the abolition of boiler-house, economizer-house and chimney stack.

Of other prime movers, there are examples in the London district of large mills driven by gas-engines. But the majority of the large mills are driven by compound condensing steam-engines with superheated steam and direct rope-drives. The power to drive a complete wheat-preparing and roller-mill plant may be taken at about 13 h.p. per sack of flour produced in an hour.

This Paper would not be complete without mentioning the flour-bleaching process by ozonized air or other agent, and that for adding enriching products to the flour in the form of fine sprays, but these belong to the domain of the chemist, and are not of direct interest to the engineer.

Grain-Handling Equipment for a Modern Flour-Mill (Section A on page 997).—Since the foregoing was written, the author has added the following particulars relating to Sections A and D (page 997). It should be noted at the outset that these are applicable to the grain store and warehouse attached to, and forming part of, a large port flour-mill as distinct from a grain store used for the merchanting of grain.

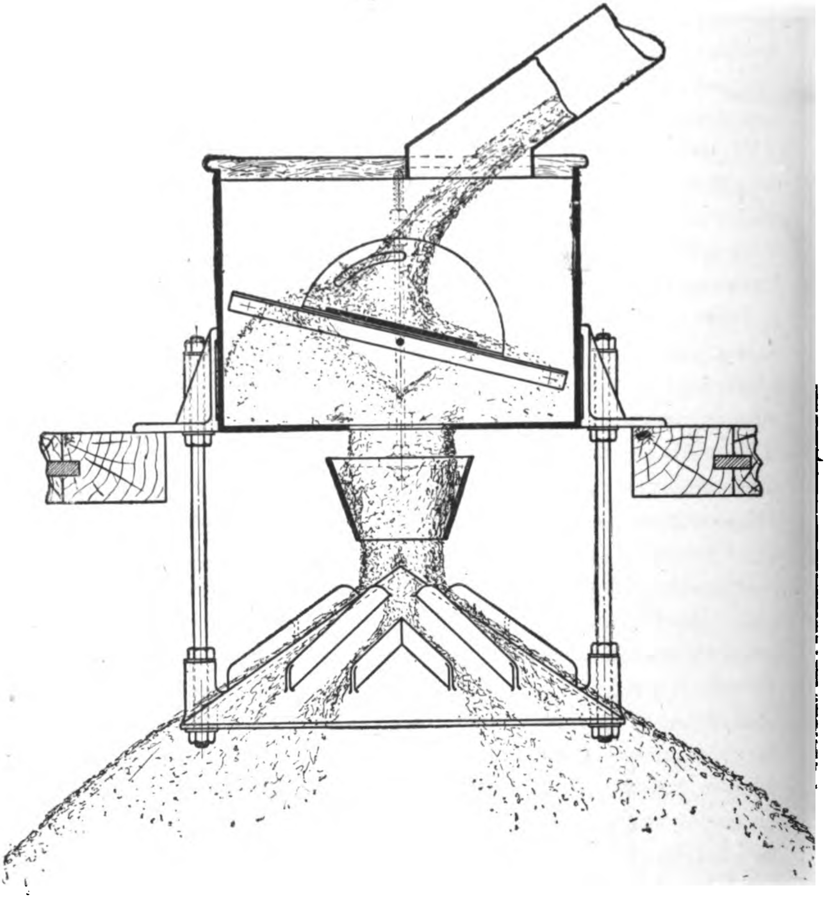
The usual equipment consists of a ship elevator on the quayside fronting a deep-water berth. The standard type used is the ordinary leg-elevator with endless band with buckets attached. The legs are suspended at, or near, the elevator head from the outer end of a balanced arm. The tower carrying the trunnions of the balanced arm may be fixed as in Plate 32, or may travel on rails laid parallel with the quayside as in Plates 33 and 34. With the elevator mounted on a travelling tower, it is able to command any of the ship's holds without the vessel moving along the berth, which is of considerable advantage. When operating, the legs are lowered into the hold of the vessel with the boot sufficiently buried in the grain to keep it fed. As the grain is lifted away, the legs follow down to the bottom of the hold and the grain runs down towards the boot until the natural angle of repose of the grain is reached, when trimming becomes necessary. The ship elevator delivers on to a travelling band running the length of and parallel with the gantry track, either in a tunnel under the quay-level or on a raised platform, so as not to interfere with the quay traffic. Arrangement is made for feeding this band at different points along its whole length. From this band the wheat will pass up a fixed elevator to the preliminary cleaning plant, consisting of an automatic weigher with recording counter for registering the number of tips, followed by a separator consisting of oscillating sieves or riddles with powerful air-currents for removing light chaff and dust. From the separators the wheat would be lifted by another fixed elevator to the top of the silo house, or wheat-store proper, on to travelling bands with throw-off carriages to distribute the wheat into any one desired silo. The rate of intake adopted in different mills varies considerably, but 50, 60 or 70 tons per hour are quite common, and 120 tons per hour is not unusual. For the latter the automatic weighers would have a bucket capacity of 2 tons, giving one tip per minute. The scale is provided with a ready means of weighing off odd residua, a refinement of great use when changing from one cargo to another, or from one bin to another.

The storage of wheat in silos has become universal in all large mills. A silo consists of a nest of receptacles of the nature of deep wells with hoppered bottoms so as to be self-emptying through an opening in the centre of the hoppered bottom controlled by a slide. The walls may be of brick, steel plate, timber or ferro-concrete. Ferro-concrete is now being very generally adopted for silo construction, though a large number have been built in timber on the American plan of criss-cross. In ground plan they vary in section according to the material adopted; for brick work the usual shape is octagonal, for steel plate circular, for timber square, for ferro-concrete square, or if large then circular. Silos when square in section vary from 8 to 12 feet square, but when circular in steel plate or ferro-concrete they may gô up to 30 feet diameter. In cases where such large diameters are adopted, the bin would not have a hoppered bottom but would be emptied through a number of outlets with trimming when requiring complete emptying. Silos are carried up to a height of 60 or 70 feet above the spring of the hoppered bottom. It will be appreciated that for a strictly automatic wheat store, the silo with the hoppered bottom is the only form admissible.

It is usual to keep the hopper bottoms some 18 feet above the basement level, so that the silo outlets can be spouted directly on to travelling bands running along the basement floor and delivering to a fixed elevator, which in its turn feeds a set of storage bins usually located in the wheat-cleaning section. Up to this point the different kinds of wheat have been stored in separate bins. From

Fig. 30.—*Wheat Distributor.*

Grain entering Silos.



the storage bins the wheat will be drawn through measurers, Figs. 28 and 29, Plate 34, to give a mixture of wheats in definite predetermined proportions for treatment on one or other of the wheat-cleaning plants included in Section B (page 997). Difficulty in the use of deep bins for the storage of wheat has occurred, due to the wheat grading itself in the bin, so that the heavier grains are discharged first, the lighter grains being held back until the bin is comparatively empty. This tendency to natural grading is obviously undesirable and detrimental to regularity of working.

Wheat Distributor.

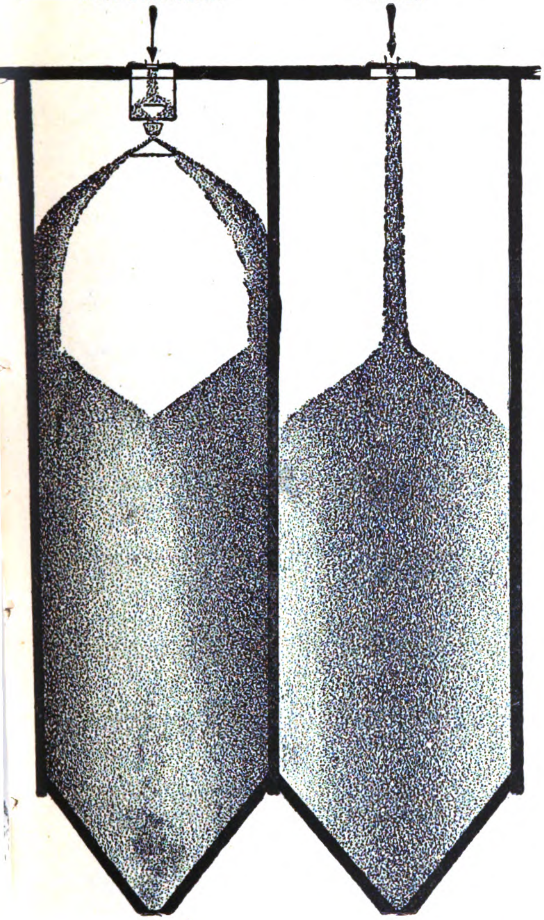


FIG. 31.—*Disposition of Grain entering the Silos.*

With Distributor. Without.

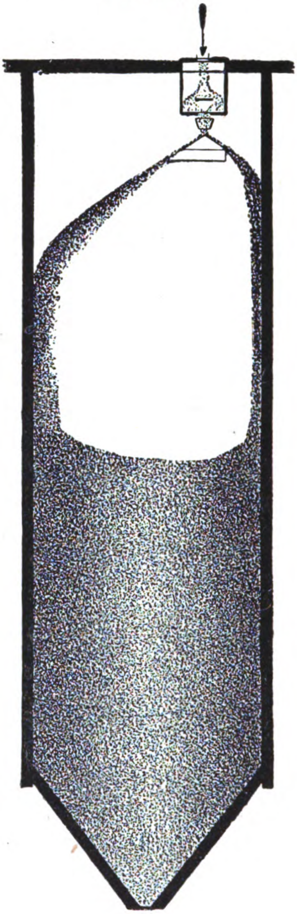


FIG. 32.—*Feed Distributor fixed for Side Feed and Central Discharge.*

To counteract this a distributing device, shown in Fig. 30, at the mouth of the bin throws the heavy grain towards the bin sides leaving the lighter grains to accumulate in the middle, Figs. 31 and 32. When the slide is drawn, the lighter grains have the first chance to flow out, Fig. 33, and the result is a more even grade, as shown by comparing the discharge curves Figs. 34–36 (page 1026).

In order to reduce the fire-insurance charges on the silo, it must be in a building by itself separated from the mill building, with special restrictions as to communication passages with fireproof doors.

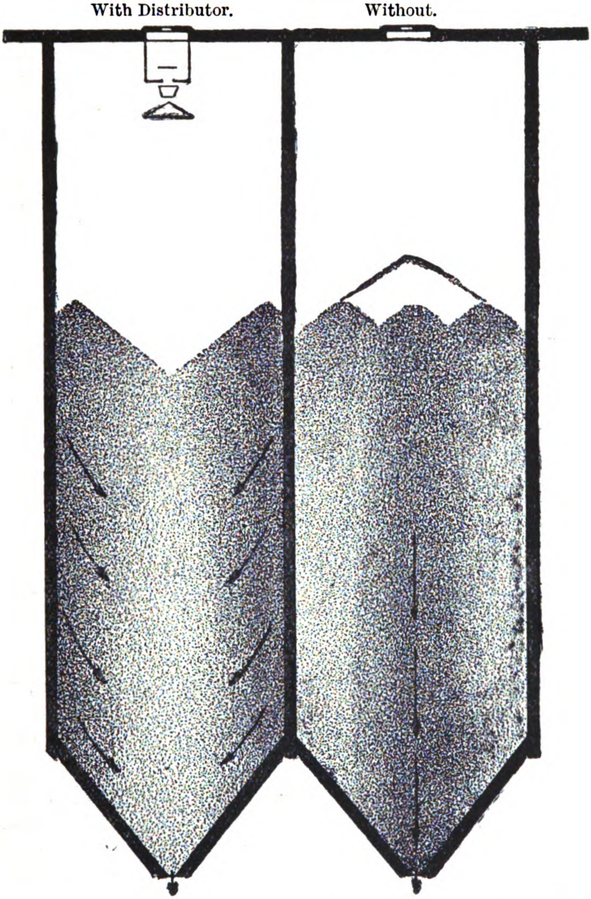
In the foregoing the author has described what has come to be regarded as the standard arrangement.

Referring again to the ship elevator, in its earliest form it was usually swung out by means of a jib pivoted on the wall of the silo nearest to the dock side, the equivalent of the elevator with fixed tower shown in Plate 32.

The labour of bringing wheat to the boot of such a fixed elevator, when the boot was down to the bottom of the hold, led to the devising of mechanical grain-trimmers. These consist of square boards held approximately vertical by means of a rope connection from the four corners pieced to a single rope running through a snatch-block in any convenient position, the rope being led to a winch either on the ship's deck or in the elevator tower. A man standing behind the board guides it through the grain heap towards the elevator boot. Such a mechanical trimmer is a great advance upon hand trimming. As a further step towards automatic action, arrangements are made for controlling the winch by pneumatic connection. For getting the wheat in the ship's hold to the lift point, the pneumatic system of elevating by air-suction through pipes was introduced, Fig. 37, Plate 35. The essentials of this system are a length of flexible hose to reach the furthest point of the ship's hold, fitted with suitable arrangement to admit air to the nozzle at the end of the pipe when buried in the grain; a well-arranged pipe-line from quay-side to silo house, with as few bends as possible, and these of large radius; a receiving tank with air-locked automatic outlet to drop out the grain; and finally, at the end of the pipe-line, an air-pump or blower to produce the necessary flow of air through the pipe-line. This system has many attractions, but has proved

Fig. 33.—*Wheat Distributor.*

Disposition of Grain as it leaves the Silos.



expensive in power-consumption and in cost of upkeep when compared with the bucket elevator.

Then, too, there is the trouble caused by dust getting into the blowing machine. It is, however, frequently found as an auxiliary

Tests made in Silos with and without the Feed Distributor shown in Fig. 30 (page 1022.)

Showing variation in lb. per bushel at different depths of the Silos.

Fig. 34.—*Test on Russian.*

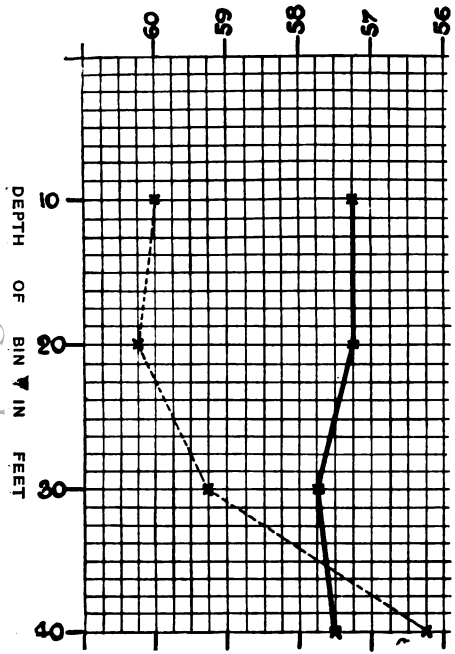


Fig. 35.—*Test on No. 4, Manitoba.*

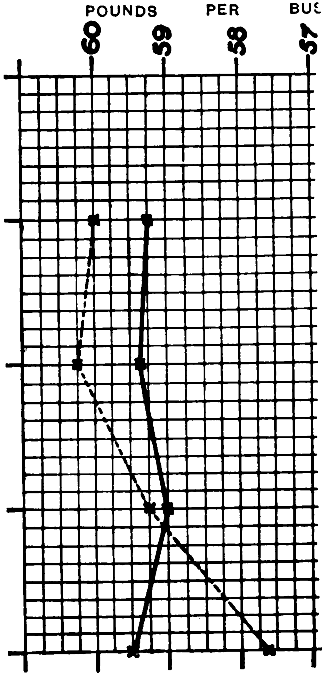
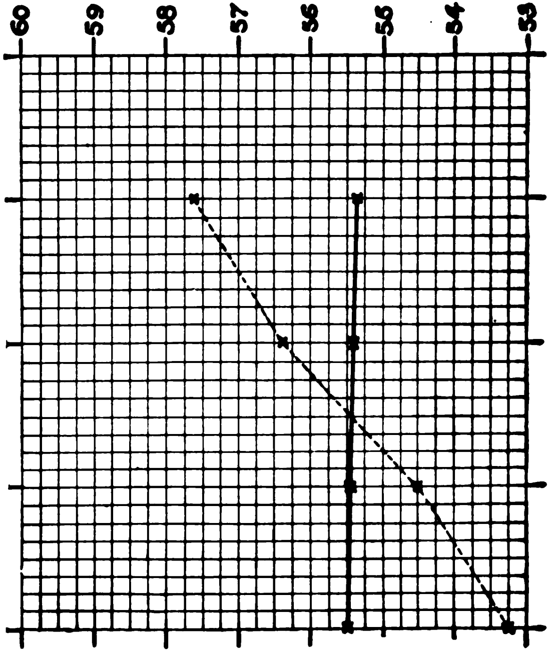


Fig. 36.—*Test on No. 6, Manitoba.*



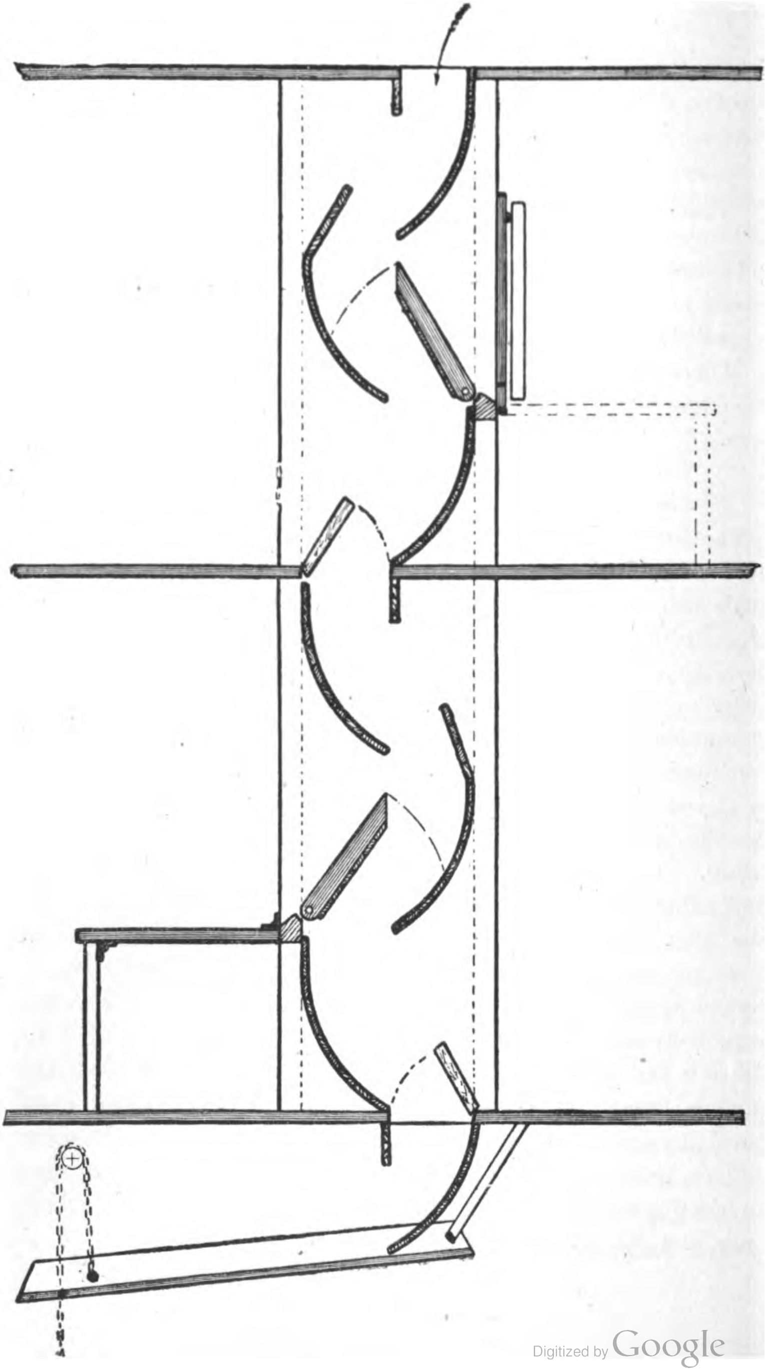
The dotted lines indicate the irregularity of delivery when the Distributor shown in Fig. 30 is not fitted; the thick lines show the comparatively regular delivery effected when using the Distributor.

of comparatively small capacity to the ship elevator of large capacity, for which it acts as a cleaner up of the corners. The question of power consumed is very closely connected with the arrangement and shape of the nozzle, which has given rise to several patented devices. In cases where wheat is carried to the mill in barges on tidal waters, as in many of the Thames-side mills and where consequently the barge is stationary on the mud for several hours between each tide, the pneumatic system of emptying is specially applicable.

The conveying and distributing of grain in bulk by means of travelling bands is so well known as to need no special description here.

Packing and Storing of Finished Products (Section D, page 997).—The introduction of labour-saving devices into the storage warehouse is of comparatively recent date. The flour, bran, and offals manufactured in the roller mill, Section C (page 997), are brought by conveyor or spout, as the case may be, through the dividing wall separating the roller mill from the warehouse. In order to minimize fire risk, and so reduce the fire-insurance rate chargeable on the warehouse, there must be no direct open-door communication between these two departments. The packing room is placed in the upper floor of the warehouse, so that, as far as possible, gravity may assist in distributing the sacks on the floors below. The flour is packed into sacks through vertical tubes depending from the conveyors and terminating about 4 feet from the floor. The sack mouth is strapped to a ring sliding up and down on the end of the tube. This ring, with the sack attached, is jerked up and down by means of a lever action, so that the sack is repeatedly bumped on the floor with the object of packing the flour down in the sack. In America a type of packer is used where the flour is forced into the sack mouth by means of a screw or auger revolving on a vertical spindle inside the tube. The sacks when full are weighed and tied up by hand, although there are machines in use for weighing the sack automatically whilst on the packing tube, and also for sewing up the sack.

Fig. 38.—*Sack Shoot.*



For sending sacks on to the lower floors the ordinary inclined shoot held the field until quite recently, but latterly, with a view to economy of space, the vertical shoot has come into general use.

Fig. 38 shows an arrangement of such a shoot designed to deliver sacks on to any one of the lower floors as desired. A vertical shoot, arranged on the principle of the spiral staircase with a continuous spiral sack run in place of the risers and treads of the ordinary staircase, makes a very compact form of shoot. Sacks can be taken off at any floor as desired.

Fig. 39, Plate 35, illustrates another form of the vertical shoot, and comprises an enclosed vertical trunk into which the sack is introduced on one of the upper floors. Its momentum at the bottom is absorbed by the curved tracks which form the termination of the shoot. The spiral sack-shoot has an advantage over the other two in that it can be filled up full to the top.

INCLINED GRAVITY SACK STORES.

Sketch shows Magazine with 7 × 11 = 77 Sack Compartments.

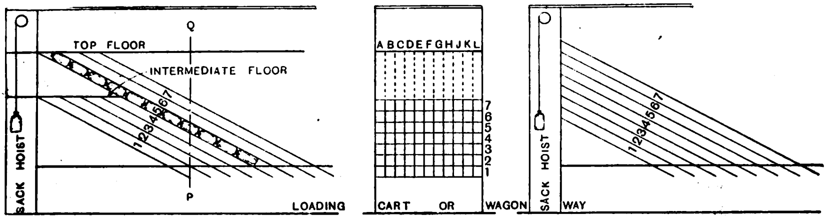


FIG. 40. *Compartments served from floors.*

Cross section on line P Q.

FIG. 41. *Compartments served from hoist.*

An ingenious device for lowering sacks from an upper floor to the quay-level outside and some little distance away was first brought out in South America. Two parallel wire-ropes were slung from the loading-out door of the upper floor to the quay-level, one on each side of the door. These wire-ropes would adjust themselves to the natural curve of repose, as there is no need to keep them taut. Short cradles were hooked on to these wires, and butting one against the other end to end formed a continuous sack-run from loading-out door to quay. When not in use, the cradles were unshipped and the wire-ropes unhooked from the quay side and stowed away.

Figs. 40 and 41 (page 1029) show a novel form of automatic discharging sack-store. The store is composed of a series of inclined sack-shoots enclosed on all four sides so that several shoots can be superimposed and arranged in tiers side by side also.

Fig. 40 shows the nest of inclined shoots fed from the ordinary floor, whilst in Fig. 41 they are fed from an elevator at one end of the range.

The lower ends of the shoots are closed by means of doors or other convenient form of lock, and deliver into a loading way for carts, or railway trucks or direct into barge as the site may require. It will be appreciated that, when once the sacks are put into the several pockets, no further handling is necessary, gravity doing the rest. A sack-counter device is fitted at the delivery end of each pocket. A warehouse on this system having a holding capacity of 2,000 tons was put up by the N.E.R. at their New Bridge Street Depot, Newcastle-on-Tyne. There is also one on the waterside at Boston, Lincolnshire, with a holding capacity of 400 tons. It is estimated that on this system one man can handle some 3,500 tons of sacks per week.

A neat fatigue-saving device, which is applicable to places other than the warehouse, is illustrated in Fig. 42, Plate 35. This device is the common bucket-elevator with platforms and hand-grips in place of the buckets. Running at a band speed of 70–75 feet per minute it is quite easy to step off or on at any desired floor while the band is in motion. A safety release-arrangement comes into action should one, in a moment of abstraction, fail to get off at the top floor, so as to prevent the person being carried over the top of the elevator.

Automatic sack-elevators, arranged so that the sacks dump themselves on any desired floor, are in frequent use.

In conclusion, the author wishes to record his grateful acknowledgment for information supplied and illustrations furnished by Messrs. Amme, Giesecke and Konegen, London; Messrs. W. and T. Avery, Birmingham; Messrs. Briddon and Fowler, Bredbury, near Manchester; Messrs. Henry Leetham and Sons, York; Messrs. Thomas Robinson and Son, Rochdale; Messrs. Samuelson and Co., Banbury; Messrs. Henry Simon, Manchester; Messrs. Spencer and Co., Melksham; the Allis-Chalmers Manufacturing Co., and the Nordyke and Marmon Co., United States of America.

The Paper is illustrated by Plates 25 to 35 and 25 Figs. in the letterpress.

Discussion.

The **PRESIDENT** thought the Institution was to be much congratulated on the receipt of so valuable a Paper, and he was quite sure that, in view of the pleasure they had received, the Members would desire to accord a very hearty vote of thanks to the author for it.

The resolution of thanks was carried by acclamation.

The **PRESIDENT** said he desired to make a few comments on the Paper, although he did not pose in any way as an expert in milling matters; on the contrary, he was really a learner of the very first principles connected with it. Those of the members who were in the same position would be much attracted by the various methods which were brought into play in order to secure pure flour. For instance: the importance which small currents of air exercised in the working; the extremely nice adjustments which must be necessary to make them effective in the different degrees in which they were required; the mechanical sorting arrangements of one seed from another, and one seed of one size from another, and so forth, must of necessity be matters of interest, especially to those mechanical engineers who had to do somewhat the same sort of thing on possibly a larger scale, where automatic working was a matter to be aimed at, and where, unless it was secured, it might

(The President.)

spell—he was going to say, disaster—certainly something very like financial disaster in many cases. He desired to mention one thing which always struck him as a subject of interest in connection with milling, namely, the introduction of metal rollers in place of the old stones. The members would recollect it was not many years ago that the daily papers lectured the people of the country to the effect that they were all slowly poisoning themselves by not eating grit; in fact, they said the proper thing to do was to eat flour which was ground with grit-stone, and that the present-day flour was all wrong. Of course the proof of the pudding was in the eating. There was no doubt about it that a much more even flour was obtained under the present system than under the old system; there must be a finer division.

There was one sentence in the Paper which he noted particularly (page 1020), namely: "This Paper would not be complete without mentioning the flour-bleaching process by ozonized air or other agent, and that for adding enriching products to the flour in the form of fine sprays, but these belong to the domain of the chemist, and are not of direct interest to the engineer." That statement might probably be quite right; very likely there were plenty of enriching products which could be added to the flour, but some people did not call them by that name. Personally, he would like to know what the enriching products were which should be left to the domain of the chemist.

There were one or two other points on which he desired to obtain further information. The author spoke of the motive power, and he gave a price at which he said electricity must be supplied in order to make it compete with steam. He would very much like to know whether full credit had been given to certain items in both cases in making that comparison. The author stated some advantages which attached to the use of steam, but he did not say in arriving at his figure whether he had given electricity the credit which was due to it from the saving in the cost of land, in building a boiler-house and a chimney, in the cost of the engine itself and in the many other ways which affected the question, whether it were as regards steam or other power, and which if the author were buying his electric power at 0·4*d.* or any other price per unit, he would save in other ways. He therefore asked whether in making that calculation the author had taken credit for the absence of a great many things which buying his power from outside in that way would result in. He had been extremely interested in the descriptions of the handling plant outside the mill itself, but he was rather surprised at the pneumatic system being practically brushed aside as altogether too expensive in the modern system. He presumed that the amount of power which had to be used in getting the suction was great, but he was a little astonished that it should be so great as to compensate for the large increase in the amount of apparatus and the amount of structure which was necessary to handle by band and other means of transmission.

Mr. C. J. **Robinson** said that he was connected with a firm one of whose specialities was Flour Mill Engineering, and he had therefore listened with considerable interest to the Paper that had just been read. He would like to take this opportunity of complimenting the author on his Paper, as he knew how difficult it was to make the subject interesting to the generality of engineers, owing to the fact that so much of it dealt with special matter. There was a good deal of information in the Paper, some of which, however, he would like to supplement.

A milling engineer aimed at making a perfectly pure article, namely, flour. If the wheat berry were opened out as it ought to be, and the interior cells converted into flour, there would be an absolutely pure article. He therefore objected to the use of adulterants, because to a great extent they were introduced in order to correct bad milling. Flour milling was an intricate process in the science of which engineers had been steadily plodding along for a number of years till at last a very high standard had been attained. Nevertheless they were far from believing that finality had been reached. A perfectly pure flour, if examined through a microscope, presented the appearance of finely divided crystals. The wheat berry itself was clothed with an outside casing of bran, underneath which were several others which constituted

(Mr. C. J. Robinson.)

offal, and all of these had to be removed in order to convert the kernel into pure flour.

The author had referred to the Americans as our great competitors in the manufacture of flour. However, the conditions of milling in England were perhaps the most difficult for the milling engineer to cater for; and in order to meet their requirements it was necessary to have a more perfect and scientific system than in countries like America; the reason being that in England the miller was obliged to grind wheats from all parts of the world, whereas America was able to grow sufficient to meet all her requirements. An up-to-date plant in England was supposed to be capable of producing a good flour from any mixture of wheat that was offered, or which it paid the miller to purchase at the time. The miller, therefore, required a far more complete milling process, as well as a more elaborate cleaning plant, in order to clean and prepare the variety of wheats which he had at his disposal. The author had given a very interesting diagram showing the various classes of wheats used in this country. Generally speaking, these were divided into three classes, namely, hard, medium, and soft wheats, some of which contained a large amount of extraneous matter in the form of dirt, stones, seeds, etc., all of which had to be eliminated before the wheat could be converted into pure flour. Not only had these wheats to be thoroughly cleansed, but it was necessary that their various characters should be assimilated. They had in fact to be brought into one uniform condition before being converted into flour.

The author had omitted to touch on one very important point in connection with this, namely, the Conditioning of Wheat, although he had referred to the washing which preceded it, and which might also be considered part of the conditioning process. The machine which performed this operation was a most interesting one, namely, the Mallinson Conditioner. The effect of the treatment was very similar to that experienced when taking a Turkish bath, the wheat went through a warming process which caused it to sweat, drawing the superfluous moisture from the inside of the berry to the surface. This moisture was then taken away by means of warm, and subsequently cold, air currents. The wheat then passed to the "conditioning" bins, where it was left for a certain time to become thoroughly assimilated before passing to the final cleaning process. It was most important that the exterior of the berry should be made thoroughly clean before the breaking-down process of the wheat took place, otherwise the resultant flour would be discoloured.

Most members were probably aware that the great difference which existed between the old stone system and the present roller system lay in the fact that with the former the wheat was ground straight away into flour, and as a natural result of such treatment the flour was contaminated with the skin, and thus became discoloured. To avoid this deleterious effect, the gradual reduction process by the roller system was introduced. It was a gradual process in that a small portion of the work was done at each operation, until the wheat was gradually reduced down and the whole of the kernel released with as little contamination as possible by the skin or branny matter. The author had rightly referred to the scalping process as a matter of considerable importance. During this operation the kernel, consisting of middlings, flour and semolina, were separated from the wheat, and it was necessary to do it in the most gentle manner possible, in order to avoid discolouring the flour. With this object the cyclo-pneumatic separator had been introduced, to which the author also referred. It was not only exceedingly gentle in its action, but most effective.

The plansifter, which was the latest machine used for separating and dressing flour, was introduced into England in a crude form many years ago. Its construction at that time was so defective that it failed to give satisfaction, and in consequence it was almost entirely superseded by the centrifugal form of dresser already referred to. During recent years, however, a great improvement has been made in the plansifter, and it was now again coming to the front. Like all things, however, which once had given trouble, their reintroduction was received with considerable prejudice, but there was no question that the plansifter of to-day was the most perfect form of flour-dresser known. The author had

(Mr. C. J. Robinson.)

given an illustration of a machine made by his (the speaker's) firm, which differed from all others in that it had two cranks, whilst the generality of machines had only one crank. The advantages of the "double crank" were that the action of the dressing was much more searching, and in consequence more perfect separations were made. This type of machine was also much easier to balance, and in fact ran absolutely free from any vibration. Some people imagined that climatic conditions affected the work of the plansifter, but this had been proved not to be so, as there were several of these double-crank machines working in India where it was well known that the monsoons made the dressing of flour a most difficult matter. It had, however, been proved that the double-crank plansifter was not nearly so seriously affected by the monsoons as the ordinary centrifugal dressing machines, and there was no question that the plansifter had this time come to stay.

With reference to the question of power, experience had shown that electric power offered so many advantages in driving a modern flour mill, that, in his opinion, there was no doubt it was the best for this purpose. It had been proved, for instance, that an electrically-driven mill could be relied on to increase the output not less than 7½ per cent. over the same mill driven by steam-power. Again, its perfect uniformity was of great assistance in regulating the air-currents, as well as ensuring evenness in the grinding and dressing of the machinery, all of which tended to higher-class production. He thought, therefore, they would be safe in accepting electrical power as the ideal drive for a modern flour mill.

Mr. Horace L. P. Boot said that it had been the business of his (Mr. Boot's) firm for some years past to make a speciality in flour, oil, and other mills of a similar kind, and although they did not claim in any way to be authorities on flour-milling, they did claim to know a little about what milling engineers had done in the past, because they had seen some of the great mistakes that had been made. There were certain reasons in this country why the mills had not speeded up their rolls. A modern mill had been erected in London quite recently in which the rolls had been speeded up, with the result that it had been found satisfactory, and more work could be done with the same amount of power previously expended, while the product was, if anything, superior. The principal reason why many of the mills had not speeded up the rolls was because the engines and the whole of the plant had been designed to run at a certain speed, which would be difficult to alter without altering everything else.

Mr. Robinson had referred to a point (page 1034) which the author had not dealt with in the Paper, namely, what was known as the Conditioning of Wheat. When he (the speaker) was first introduced into the practice of flour-milling, the method of grain-drying came as a great surprise to him, especially when he found that mills, which had the whole of their plant run by electricity, installed a small steam-boiler to heat air for the purpose of drying the wheat! That certainly seemed a long way round to arrive at the condition desired, namely, the drying and extraction of moisture for the conditioning of the wheat. Personally, he thought the proper way to dry wheat, where there were no steam-boilers in a mill, that is, where it was being run by electricity or other motive power, was, not to generate steam and then to let that steam heat the air, but to heat the air straight away with an ordinary slow-combustion stove or some type of furnace of that sort. He knew that certain firms had tried that system and condemned it, but he thought they had done so without trying to improve the faults. He ventured to think that if the system were carried out in a correctly designed stove, the economy which would result would be far greater than had hitherto been the case.

With regard to the question of barge-elevators and suction-plant, his firm had had some experience with both systems, and the result appeared to be that the suction-plant took at least 30 per cent. more power than ordinary elevating plant of the bucket type. Another question of interest was the power per sack that was used. The author mentioned (page 1020) that the power might be taken as 13 h.p. per sack of flour produced per hour. No doubt the author was as well aware as he (Mr. Boot) that the power in every mill varied enormously per sack. Some mills went in for very much

(Mr. Horace L. P. Boot.)

better conditioning; they put in a more perfect cleaning plant and turned out a better product, with the result very often that the horse-power taken per sack was more, and the value received for the flour was also more.

He was very pleased to hear Mr. Robinson advocate the use of electricity, but he could not quite agree with him. The speaker's firm had recently gone into the question very carefully in a large mill, and he had some figures with him which he thought would be of interest to the members. They considered the question of the mill engines, taking the most economical type probably, as "Uniflow," with rope transmission direct on to the roll-shafts. The whole of the mill was driven by the engine direct, with ropes, and the other part, the conditioning, or what might be termed the smutter house, and all indirect drives were driven electrically, the same engine being used for running a generator coupled direct, and carrying cables to the indirect drives. Allowing a very handsome margin for loss in the engine, and assuming that a modern boiler plant, with superheaters and high-pressure boilers, was being put down, with the uniflow engine, the price at which electricity would have to be supplied equal to it, worked out about 0·33*d.* per unit. He was assuming that the mill ran 144 hours per week, like all flour mills, and that it had a very high load factor, all the plant practically running with the exception of the intake plant. The figures came out as follows: Taking a turbine and electrical drive, the capital outlay was roughly somewhere in the neighbourhood of £7,000 for the power-plant and the total running costs at £3,800. If the motive power were taken at the figure at which several flour mills were now obtaining power, that is, ½*d.* per unit, there would still be a certain amount of capital outlay on motors, which amounted to £2,704, with running costs of £6,000. With the most up-to-date type of mill-engine, and good drive with a rope race, the capital outlay would come to £5,890, and the running costs for fuel, including everything, to £3,393.

Mr. J. E. Speight (Messrs. Amme, Giesecke and Konegen) heartily congratulated the author on the able manner in which he had prepared his Paper. He desired specially to mention the novel genealogical Milling Tree (page 997), by which the non-milling members of the Institution would be able to obtain some insight into the principles of flour manufacture. As the President had said, the system was not very simple, but the whole question was set out in a very simple manner in the diagram to which he had referred. He had not attended the Meeting with any special intention of speaking, but rather to learn something from the remarks of other people, because he very often found that when people who were not connected with a special industry would devote their attention to it, the people connected with the industry always learned a great deal from having fresh minds brought to bear upon the different points raised. Many people, when they went round a mill and saw the multiplicity of machines which were necessary, said, "Why is it necessary to have all these machines and such a complicated process? Why is it not possible to invent some process whereby at one single operation the whole of the skin could be stripped from the wheat?" If any member possessing special inventive powers could invent such a process, his fortune would be made. It was the very thing that all millers would like to do. There was one great difficulty, however, in the way of accomplishing that result, namely, the shape of the wheat berry itself. Probably most of the members were aware that the wheat berry had a crease in it, which extended internally nearly three parts of the way into it. The skin of the wheat was around the surface in the crease, and therefore any attempt which was made to clean the wheat left the skin remaining on the surface inside the crease. That was the one great reason why the milling process appeared so complicated to the lay mind at the present time.

The author had dealt very ably with many of the points in connection with the flour-milling industry, and had largely avoided any controversial matter, because that did not come within the scope of a Paper of such a description, as it very often appertained more to the system than to the machine. When the roller system was first introduced, a great deal of controversy

(Mr. J. E. Speight.)

arose. Millers were divided into two parties, those in favour of the roller system and those in favour of the stone system, but in the end the roller system had won. There had not been any very great controversy for a number of years until recently, when, owing to the introduction of the plansifter, the millers divided themselves again into two parties, namely, those in favour of adopting the plansifter and those in favour of retaining the centrifugal machine.

Mr. Robinson had put the matter very clearly when he said that the object of the miller was to produce a pure flour free from offal, and Mr. Robinson would agree with him when he said that one of the reasons why the plansifter had been introduced, and was being largely adopted at the present time, was that it was claimed that it produced a very clear flour such as could not be produced by the centrifugal, because the centrifugal had a beating action which forced the stock through the meshes of the sieve according to size only; with the plansifter, however, the stock lay on the surface of the sieve and was graduated by the rotary motion of the sieves, so that the lighter and impurer particles rose to the top and the pure flour fell to the bottom of the sieve and passed through it in its purest state. Several points of controversy had arisen in regard to the different kinds of plansifters in use. An illustration was given on Plate 29 of a machine with two cranks, and on Plate 30 a machine with one crank. A still further development of the plansifter idea had taken place. In both of the machines illustrated the spindle containing the crank-pin, by which the eccentric motion was imparted to the machine, was quite rigid and was contained in fixed bearings; but the latest type consisted of practically the same form of machine, almost the identical type of spindle-crank and balance-wheel, but the spindle in no case was fixed. The spindle was suspended by means of a swivel bearing from above, and the only other bearing was in the rotating part of the plansifter. It was claimed that by means of that motion there was far less vibration, and also certain advantages in the sifting.

He thought Mr. Boot (page 1036) must have been unfortunate in the machines he had seen; at any rate he thought Mr. Boot should not overlook the good work and good examples that had been carried out by the several engineers in the trade. No one was really infallible, and even the best of engineers must make mistakes at times. Mr. Boot also raised a question about the high speed of the rolls. He gave a concrete instance of where the rolls had been speeded up, and a saving in power had taken place. But from a miller's point of view, power was not everything. The miller had to look very much more to the final results in the flour sack. He would not carry the matter further, but would simply say he did not agree with what had been said by Mr. Boot in regard to the high speed of the roller mills.

With regard to the question of drying the grain, it was not at all necessary to adopt the process which was in operation in several places, that is, to have a small boiler to raise the steam and heat the air by those means. On the Continent there were numerous mills driven by water, and therefore the conditions would practically be the same as would obtain with a mill driven by electricity, where no steam was available. For that purpose there were several firms who made a specialty of providing a proper heating arrangement for air, exactly as Mr. Boot suggested might be of advantage.

The question of the pneumatic conveying of grain was also not a question solely of the cost of the power. When the system was applied chiefly for discharging cargoes from grain steamers, then there were many considerable advantages which certainly made the power question not of such great importance. He thought it could be taken as granted that for such an installation as was shown on Fig. 37, Plate 35, the power would be somewhere about 1½ h.p. per ton of grain moved, or even up to 2 h.p. The advantages were that the steamer could be discharged very quickly by considerably fewer men, because the grain had not all to be trimmed and brought to one point for the bucket-elevator to deal with. Flexible tubes were put into the grain, so that no labour whatever was required to lift it. Another point was that, in certain classes of the grain trade, many of the cargoes which arrived consisted of a large number of parcels of different kinds of

(Mr. J. E. Speight.)

grain, and different marks of the same kind of grain. Very often some of them were only in small lots, and they were parted in the holds of the vessels sometimes by tarpaulins and sheets and at other times by boards. In such circumstances the pneumatic discharging plant was a great advantage, because the small parcels were very quickly cleared out.

Mr. E. R. **Dolby** desired to ask a question, not as an engineer but as a consumer. The whole of the elaborate process which had been described seemed to be used for the purpose of separating the white portion of the berry for human consumption. He desired to ask whether the white portion of the grain was the only part that was really useful for human consumption, containing nutriment in such a larger percentage than the rest that it was not worth while to eat any of the rest; or was it merely a requirement of fashion that the flour should be white? Assuming the latter to be the correct explanation, then, if the dictates of fashion were ignored, could not several processes and much expensive machinery be eliminated, and flour-milling be thus rendered less costly?

Dr. H. S. **Hele-Shaw** (Member of Council) said he thought it would prove of use if the author would explain a little more clearly the question of the distribution of the wheat in the silos. From the speaker's Liverpool experience, he knew that when the silos were first introduced many years ago they created quite a revolution in grain storage, and the question of the distribution in the silos was such an important one, that the information, either by a diagram or in some other way, as to how it was that the heavier grains went down first and left the lighter ones behind, would be most interesting.

Mr. **Robert** B. **Creak**, in reply, said that in view of the lateness of the hour he did not propose to wander into the region of enriching materials for flour, as it was too thorny a question. The members probably knew that a Pure Foods Bill had been projected in Parliament. What effect it might have on the subject under discussion he did not know; at any rate he was not going to deal with it. With regard to the question of motive power, his calculation of 0·4*d.* per Board of Trade unit was based on a calculation which allowed for the capital outlay for power, an allowance for depreciation, for upkeep, cost of chimney, cost of buildings and stores, but it did not include any figure for land. He quite admitted that circumstances sometimes occurred where the saving in land outweighed any question of economy, and there undoubtedly the electric drive should be adopted. He knew of a case of a mill in London where there was no room for an engine and boiler-house and a chimney, and for such a place electric driving was the thing. But for a mill which was not cramped for room, and where land could be obtained at a reasonable price, he was inclined to think that a modern steam-engine with superheated steam at a high pressure, with direct rope-drives, was the cheapest form of motive power. A point of considerable importance in connection with the subject was that the ordinary millwright who looked after the mill machinery could only look after the upkeep of the engine; but if electric plant was installed, it was necessary to employ an electrician for that particular job and for nothing else, whose wages were fairly high. That was an added expense.

In regard to pneumatic elevating, there again the same sort of consideration came in. There were cases where the conditions were such that the cost of pneumatic elevating did not count; convenience was paramount. Taking the case of many of the London mills, where the barges lay on the mud for a good part of the tide, several hours of the day, there the fixed bucket-elevator was obviously inconvenient and unsuitable, and for such a case as that probably the pneumatic-elevator should be adopted. But it was undoubtedly expensive in power, and it was, he thought, somewhat difficult to keep in repair, because there was no more successful abrader than wheat mixed with sand. Some foreign wheats contained a considerable percentage of fine silica which would cut through anything. He had seen it cut right through ¼-inch plate glass, and therefore the upkeep of a pneumatic plant was fairly high.

(Mr. Robert B. Creak.)

Mr. Robinson had mentioned the question of the conditioning of wheat (page 1034), which was a most important and delicate operation. He had heard it said—and he was inclined to agree with the statement—that the most critical part of the mill was the conditioning-room. He ventured to think that no very radical improvement had been made recently in that direction, and for that reason he did not touch upon it, as he did not desire to traverse old ground which had been dealt with in the late Mr. Henry Simon's Paper. He thought he was also right in saying, in connection with Mr. Boot's remarks on conditioning, that at the present time a large number of mills were not using their heaters at all, and were not conditioning their wheat with hot air, but with cold air only. The hot-air fan was kept going, but cold air was used instead of hot, and that to a large extent had overcome the difficulty of the want of steam in electrically-driven mills.

Mr. Robinson declared very emphatically for electric power. It was admitted, he thought, that greater regularity of running was obtained when electric power was used, which was important, as he mentioned in the Paper, where so many separations were made by air currents. At the same time he was not aware that such a marked increase in output as that mentioned by Mr. Robinson was obtainable from electrically-driven mills. He was very interested to hear that statement, and would like to make further inquiries about it. Mr. Boot's figure of 0·33*d.* per unit came fairly near to his own of 0·4*d.*

Mr. Speight had mentioned what he (the author) called the free-spindle plansifter. That was, he thought, a very beautiful improvement. As Mr. Speight had stated, it consisted of a freely suspended spindle instead of the vertical spindle and rigid stand that was seen in the plansifter depicted in Plate 30. The spindle, instead of being underneath, was hung from the top, and was attached at the top to the roof trimmers or the ceiling, as the case might be, with the driving pulley close to this attachment. Beyond that, the spindle was free to swing like a pendulum. It was attached at the bottom to a crank having a crank-pin at one end and a balance-weight at the other. When started, the depending spindle swung round freely. There was action and reaction between the balance weight and the plansifter frame, the resulting motion being a steady rotation with no vibration transmitted to the building. Mr. Dolby (page 1042) had referred to the value of white flour. He directed that gentleman's attention to the *Daily Mail* as the best authority on the subject.

Communications.

Mr. W. Worby Beaumont, referring to the self-balancing plansifter mentioned during the discussion, wrote that the plansifter was operated by a form of the mechanical motion known as the Vibromotor as invented by him in 1892–3, and used in some forms by Messrs. E. R. & F. Turner, and by the Hardy Pick Co. in England, and by the Allis-Chalmers Co. in America in their Universal Bolter with superposed sieves. Some of the forms of screening machinery thus operated were described and illustrated in the Journal of the British Society of Mining Students in 1900, the Journal of the Society of Arts in 1894, and in the Journal of the Liverpool Engineering Society in 1895.

Mr. George Briddon (Stockport) wrote that the author had dealt with his subject in a very terse and lucid manner, but had so carefully avoided giving any opinion of his own as to the merits or demerits of the machines and methods he had referred to, confining himself to description only, that he had left very little for discussion.

Referring to his opening paragraph, one would be led to conclude that, owing to what he termed the "modern tendency" to locate flour mills of large capacities on the waterside at the principal ports, the inland flour mills, and especially those of small

(Mr. George Briddon.)

output, would soon be a thing of the past, on the assumption, of course, that the inland mill would not be able to compete with the large port mill. If such was the author's opinion, he (Mr. Briddon) was not in agreement with him. The advantages were not all with the port mills, and he was convinced that there would always be room for the inland town and country mills, provided they were equipped in the best possible manner, and were of a capacity to suit the requirements of the immediate district so as to enable the finished products to be disposed of without much expense in delivery. If the mill were situated in a wheat-growing district, the native wheats were generally delivered to the mill as cheaply as they could be put on rail, and an advantage was thereby gained. Again, the bran and other offals met with a ready sale in the locality, and were very often delivered to customers at the mill door, the prices obtained being, as a rule, much better than the port millers could get, for the reason that the port miller produced a much larger quantity of bran and offals than he could dispose of without resorting to railway transit, and very often he was compelled to export them at low prices; further, the inland miller came in close touch with his customers, which was no small advantage.

He would like to point out that the classification of the processes (page 997) were not confined to port mills; a large number of inland mills were similarly provided for, excepting that barges took the places of ocean vessels. The process described on page 1009, and illustrated by Fig. 10, was the invention of the firm with which the writer was connected, and some very marked advantages were to be obtained by it.

He could not understand how the author had arrived at the conclusion that, on account of the settling chambers in the upper part of the air-belt purifier, as illustrated by Fig. 17, Plate 28, "the sieve is not so easily visible." The machine referred to was one manufactured by the writer's firm, and every care in designing it was exercised to make it perfectly accessible to every part, and the action of the sieve could be as easily inspected as on any other type of purifier. The advantage of a purifier on the air-belt principle over one continually drawing in air was that the product being treated did not lose any of the moisture it contained, and loss from evaporation was avoided; moreover, the results from it were more regular, because a greater or less moisture in the surrounding atmosphere did not have any effect on the results.

Mr. **William H. Glaser** (Manchester) wrote that, among the many details of flour-milling mentioned, the following particulars might be specially interesting to members.

The rolls used in a roller-mill were made from very hard, close-grained, chilled cast-iron, and were first turned before they were ground. A broad flat turning tool was used, ground to an angle of about 87°, and a low cutting speed, less than 10 feet a minute, was found to give good results. The turnings came away as long thin needles. After the rolls had been turned, they were ground, and had to pass a severe test for cylindricity. They were set in a frame, with their axes horizontal, one above the other, and a light was passed along behind them, opposite the line where they touched. If necessary, the rolls were re-ground until no light could be seen between the rolls. The man who made the test became wonderfully quick to detect a leakage, and when the rolls passed the test they really formed a light-tight contact.

The balancing of plansifters was carried out to a high degree of accuracy; the author had mentioned how plansifters were often run with the holding-down bolts removed, by way of test or demonstration. If the plansifter was balanced with its trays empty, there would be a departure from perfect balance when the machine was at work, especially if the feed were heavy, on account of the capacity of the trays. Plansifters had therefore been devised with a wide range of unconstrained motion in the horizontal plane, except in so far as the parallel pendulum suspension constrained the motion to be circular. When such a plansifter was set in motion, the radius automatically adjusted itself to give perfect balance, but the sieving capacity—the amount of stock which the sieves could pass in an hour—was correspondingly varied. This was, of course, not a drawback, although the sieving capacity was

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found not to vary in any simple relation to the radius of the circular motion, for the capacity depended also on the depth of stock on the sieve; it was merely a point of passing interest to the engineer. Such self-balancing plansifters were designed in two styles. In one the motion was transmitted direct to the plansifter sieve-carrying frame; in the other, it was transmitted direct to the balance-weight, as was the case in the Fraser sifter, and the sieves were set in motion by the reaction of the balance-weight. The tautness of the sieve clothing, not only in plansifters but in other sieving machines too, had an astonishing effect on the sieving capacity, and some difficult but interesting problems had arisen.

The plant used for adding enriching products to flour had many points of interest to engineers, though the process, as the author had said, was for the chemist to discuss rather than for the engineer. The ram-pumps for supplying the spraying-nozzles had a diaphragm for keeping the liquid out of contact with the working parts, an adjustable by-pass to enable the pump automatically to deal with a variable load without excessive rise of pressure on the one hand, or serious loss of pressure on the other; for it was important to keep the pressure on the spraying-nozzles within certain limits to secure sufficiently uniform treatment of the stock.

The mixing tanks were carefully designed in earthenware to be easy to clean out, and to be free from pockets at such places as the delivery-pipe joint where liquid might otherwise lodge; they were fitted with air-lift mixers, also of earthenware. The air-compressor for the spraying-nozzles had a dust arrester on the intake-pipe, and an oil-separator on the delivery-pipe. The spraying-nozzles themselves embodied the results of much careful experimenting.

He had purposely given, in dealing with the engineering features of sieving and enriching processes, the merest outline of the many points of interest, lest engineers who did not happen to have had to do such work of experimenting, designing and calculating in connection with them as the writer, should find them not attractive. Engineers would also take an interest in the action of pulsating water in separating, from wheat, small stones of very nearly the same specific gravity, and of air currents in purifying flour-mill stocks.

Mr. GARDINER MITCHELL wrote, with regard to the wheat-preparing plant (page 998), asking if it was generally accepted that the method of removing the dust by wind currents ought to be by aspirators and not by blowers. The wheat was mentioned as rolling out of the pits of the indented cylinders (page 999), but he thought the berries never entered the indentations at all (when extracting cockle seeds); but in the case where these cylinders were fitted for the purpose of separating barley, oats or straw from wheat, the grains being the smaller went into the indentations, and were carried up, falling into an adjustable tray, thus allowing the barley, oats and straw to work towards the end and deliver over it. He thought that the machine illustrated in Figs. 3 and 4 (pages 1000–1) was an improvement in some directions; at the same time, the up-keep of this machine and power consumed would, he presumed, be greater than with the cockle cylinders; it would also require more attention, and, bearing all these points in view, the benefits obtained would not probably warrant a change.

He agreed with the author that the more economical method of feeding the elevator (page 1020) was by a mechanical trimmer, and Fig. 43 (page 1050) showed four of these applied to a floating elevator; also Fig. 44 showed the elevator boot of a fixed barge elevator, on which it would be noted that just over the boot there were fitted rollers horizontally and vertically for the rope to run on, so that it might pass between the legs of the elevator on its way to the winch.

It was mentioned (page 1020) that an arrangement was made for feeding the band at different points. This could be accomplished by a series of trap-doors along the quay on top of the band, and the elevator shoot could be telescopic to reach the nearest available one when working. In the second line of page 1021, the author referred to "an automatic weigher with recording counter for registering the number of tips." It was presumed he meant the number of

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Fig. 43.—*Mechanical Coal Trimmers for feeding Elevator.*

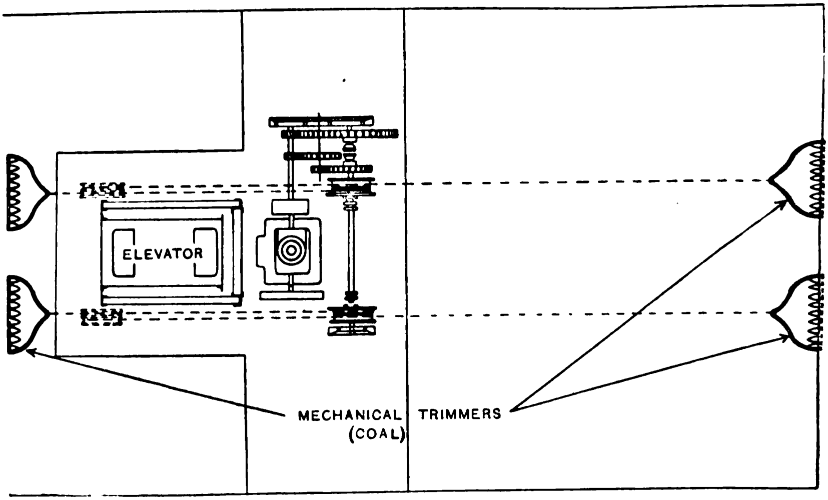


Fig. 44.—*Elevator Boot. Elevator speed 320 feet per minute.*

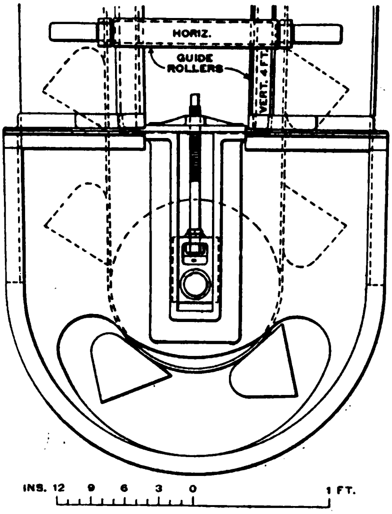
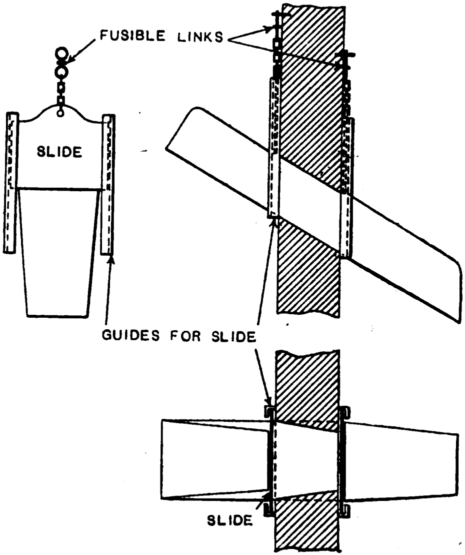
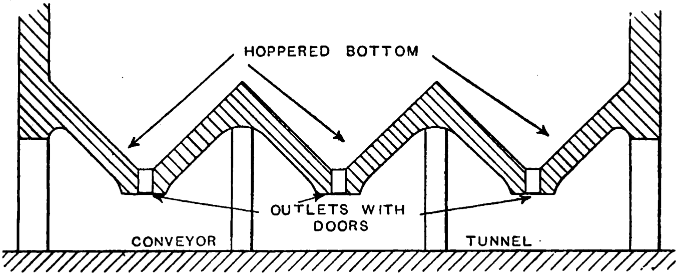


Fig. 45.—*Wall Shoot with sliding doors held by fusible links.*



weighings. On the same page regarding silos, he thought it was always advisable to hopper the bottom of them, because, if flat-bottomed, it would require additional labour to remove the grain which could fall out; but he noted the author said that in cases of large diameters the bottoms were not hoppered. The writer was of opinion that it would be a more efficient silo if the bottom were hoppered, however large, as this could be done by having a few outlets and hoppering the bottom to each, as shown on Fig. 46. With regard to storing grain in silos (page 1023), when designing such a plant it should also be arranged for the grain to be "turned over" periodically by emptying and refilling the silos with the same grain if it was being stored for some time; heating, sweating, and deterioration would thereby be prevented, especially where dirty grain was being dealt with.

Fig. 46.—*Large Silo Bottom, showing Hoppered Outlets.*



It was stated (page 1026) that the earliest form of elevator was swung out by means of a jib pivoted to the wall. The writer did not think it was a case of the earliest form, but that the reason for this design was owing to confined space where the warehouses were close to the water.

With respect to fire-insurance rates (page 1027), the writer had found it necessary, when arranging a shoot through a wall, to fit a sliding door on each side of the wall; these were held by fusible links so that, when the heat became excessive on each side of the wall, the slides dropped down on to the bottom plate of shoot, as shown on Fig. 45. These fusible links were also suitable for

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keeping open fireproof doors of communication passages, mentioned by the author (page 1026), the doors being arranged to close immediately the heat melted the fusible metal in the link.

Mr. E. D. Simon wrote that the first thing that would strike anybody on reading this Paper was the number and variety of the different processes which a flour-milling engineer had to deal with. They might be divided roughly into two main sections:—

1. The problems of dealing with the handling and storage of the wheat and products; and

2. The actual wheat cleaning and milling operations.

Handling and Storage of Products.—The problem a milling engineer had to face was, roughly speaking, to adapt certain well-known contrivances for handling and storing grain to the special circumstances of each individual case, having regard to a proper adjustment of capital expenditure and working costs. One had to foresee the exact operations which were likely to be necessary, allowing for the probable growth of the capacity of the plant, and decide how far it was advisable to go on putting in expensive plant to save manual labour. In many cases a good deal of thought and ingenuity was required to arrive at the best solution. On this side there were two engineering problems of special interest. The first one was the determination, in the case of wheat or other grain storage in deep bins, of the pressure exerted by the grain on the bin wall. This was a matter on which a large number of experiments had been made, and fairly reliable results were at present available, though it would generally be agreed that even now further tests for different shapes of bins, with outlets in varying positions, would be useful.

The second interesting problem was the pneumatic transport of wheat, which had been referred to by the author. This had during the last few years become an established part of the practice of grain conveying. Some of the conditions which affected the choice between the bucket elevator and the pneumatic elevator had been well indicated by Mr. Speight (page 1041). One of the special difficulties of pneumatic conveying was that, owing to the large amount of dust in the wheat, the air pump had to deal with exceedingly gritty air. In the early days of pneumatic grain-conveying this caused continual difficulty, but several excellent pumps had now been designed which would deal satisfactorily with air containing a fairly large proportion of grit, in continual running.

One of the points in which pneumatic transport would no doubt be further improved was as regards power. The power taken for an average plant might now be said to be between 1½ and 2 b.h.p. per ton of wheat lifted per hour, which, as the author pointed out, was considerably greater than that of the ordinary bucket elevator. The theory of the quantity of air required to lift a given amount of wheat, the pressure necessary, the determination of the area of the pipe, the form of nozzle, and so on, presented a number of engineering problems of the highest interest and difficulty, and offered a large field for experimental work.

Wheat Cleaning and Mill.—In this department there were two types of problem: firstly, engineering problems, and secondly, purely milling problems. Both of these had been dealt with by Mr. Creak. The characteristic of all these problems, except the ordinary engineering problems which occurred in most factories, was their complication. Take, for instance, the power required to drive the various machines in a mill, a question which the writer dealt with in detail in a Paper read a few months ago before the Association of British and Irish Millers.

One or two instances of this complication might be of interest. The machine requiring most power in a flour mill was the roller-mill. In most modern British mills, roller-mills were required for three kinds of work as indicated by Mr. Creak: break roller-mills, reduction roller-mills, and bran-rolls. He had worked out formulæ showing the power required in each case. The three formulæ were entirely different, and each of them depended on several different factors, some of which were continually varying. Similar formulæ could be devised for all the other machines in the mill. Generally speaking, the power required to drive a roller-mill

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plant of a given capacity (omitting the wheat cleaning) depended chiefly on the following factors:—

1. The number and size of the roller-mills in each of the three sections.
2. The type of dressing machines used, whether plansifters, centrifugals, or a combination.
3. Type of purifier plant used.
4. Kind of wheat on the mill.
5. Condition of the wheat on the first break.
6. Fineness of the flour which it was desired to make.
7. Whether any of the offal was ground up.
8. The percentage of flour which was required from the wheat.
9. The usual engineering problems with regard to the arrangement of drives, transmissions, etc.

It would be seen from this that the engineering problems in a flour mill were sufficiently complicated, but the milling problems were infinitely worse. The basic problem was that of separating the husk of the berry from the kernel, and the fundamental difficulty was that no such thing as a perfect separation existed or probably could exist in a flour mill.

Dealing first with the question of wheat cleaning, perhaps the most important part of the cleaning process was the aspiration and the separation of the light from the heavy particles. It had been found by careful experiments that, if a given separation of impurities was aimed at by means of aspirations, a certain percentage of the impurities could be got out by one aspiration, a further small percentage by a second aspiration, and so on, and undoubtedly in practice a considerably better separation could be obtained by a treble aspiration than by a single one. The standard practice was, however, to have a single aspiration on most of the wheat-cleaning machines. In a good mill the wheat would often be aspirated seven or eight times after it was received before it went to the actual grinding mill. Of course, most of the processes of wheat cleaning produced fresh dust, which again had to be removed. It was, as stated above, impossible to get a scientifically accurate separation. All one could do was to aspirate over and over again, and more or less trust to luck. Perhaps the most scientific way of dealing with this particular question was to aspirate too heavily, so as to get nothing but perfectly pure wheat on the first break, and then make the best possible separation of the material which had been drawn away, separating it into one part which contained all the light but still fairly good wheat, and another portion which consisted only of screenings, chaff, and refuse. The former part could then be ground on a separate small mill, and might yield, say, 50 per cent. of fairly good flour. This, however, was a method open only to a large miller, and too expensive for a small miller to carry out.

Turning now to the question of actual milling separations, perhaps the best illustration of the difficulty of the problems met with was the old controversy of Plansifters versus Centrifugals. The author had dealt with this at some length. The difficulty was well illustrated by the fact that in the Paper read by Mr. Amme before the Association of British and Irish Millers a few months ago, supporting the plansifter against the centrifugal, Mr. Amme confined himself exclusively to the mechanical problems, and hardly attempted to deal with the question of the separations which could be made on a plansifter. The mechanical problems in connection with a plansifter were no doubt difficult, but it was universally acknowledged that they had been practically solved now, and there was no particular difficulty in building a plansifter which would work satisfactorily. Mechanically it was also quite possible to weigh the relative advantages and disadvantages of plansifters and centrifugals. The plansifter took less space and less power. It was, however, a much more complicated machine than a centrifugal. There were, further, big forces continually at play which were a potential source of trouble, so that the machine required a higher degree of engineering skill to keep it at constant and satisfactory work. In addition to this, owing to the greater complication of the plansifter, it took a longer time to effect any small repairs. For instance, a hole in the silk of a centrifugal could be repaired without stopping the work of the machines at all, whereas a plansifter had to be stopped probably for half an hour. In a small

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or moderate-sized mill this would actually entail the serious disadvantage of having to take feed off the mill.

When, however, we came to the question of the separations made, we found that, notwithstanding thirty years of experimenting all over the world, there was no unanimity of opinion. It was boldly claimed by the advocates of the plansifter that it was gentler in its separations, and that it at the same time made more accurate separations. On the other hand, the advocates of the centrifugal denied both these statements, and said the plansifter was much influenced by variations in the humidity of the atmosphere, so that the milling results were irregular. There was little doubt that the decision as to whether to use a plansifter or a centrifugal was, to a large extent, a matter of fashion. Many of the best millers, especially in Germany and Austria, were strong advocates of plansifters. On the other hand, some of the largest and most successful millers in this country would have nothing to do with them, though they had in most cases tested them carefully, stating generally that the reliability of the centrifugal outweighed any advantages claimed for the plansifter. The problem was not yet solved, and he said unhesitatingly that it was impossible for anybody to-day to lay down general rules and to give any really scientific evidence in support of these rules which would be conclusive in determining which of the two machines was, generally speaking, the better.

All problems still facing the miller were so complicated, and were affected by so large a variety of causes, that an enormous amount of careful, detailed, and patient research was necessary before any dogmatic statements on many of these milling problems could be justified.

Mr. Gilbert C. Vyle (Birmingham) wrote that the author commented favourably (page 1019) on the adoption of electricity as motive power for mills, but required a supply at 0·4*d.* per unit to compete successfully with steam. He did not know if there had been included in this figure advantages gained by electric driving, which were difficult to translate into exact figures. Nevertheless, if an attempt were made to value these advantages, he thought the economy would be shown to be on the electric side. The same problem faced the textile mill engineers, when it was found that the steadiness of the motor drive with little or no peripheral speed variation was of the maximum importance, as it resulted in a greater output of better work. Flour mills would appear to be in the same category.

There was also a great economy in space, and greater ease in starting up and closing down. Rope drives gave excellent service up to the point when the rope required to be renewed. This renewal point was difficult to indicate or to anticipate. Engineers were tempted to carry on rather than incur expense in complete renewal, and then trouble came at the very time when it could be done without. A further and important argument for the adoption of electrical driving was, that if the different processes were divided up as suggested in the Paper and independently driven, a recording watt-meter in each motor circuit would give a continuous record of what had gone on throughout the whole run. It would show if the machinery was being properly maintained and running with the minimum friction. It would also show what stoppages had occurred, and whether the load had been constant or variable. In fact, with proper data of current consumed in certain known conditions, the engineer and the manager would be able to read the whole week's record, and obtain important clues for investigation to enable them to maintain their machines in the highest state of efficiency.

With the continual adoption of additional machinery in every line of manufacture, and the constant striving to make the latest type of machine do substantially more and better work than the machine which it superseded, production costs were governed by the efficiency of the machinery and the process, and he submitted that, in the modern flour mill, the engineer must be continuously furnished with figures giving him the bases to discover his machinery efficiency. In the complete mill, as described by the author, it appeared very necessary to be able to record the weight of the product at all stages of manufacture. For instance, the

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grain taken from the ship should be weighed on its way to the silo or store-house. This was essential, for the mill-owner should only pay for what was actually delivered. The shipping weights and advice notes which he received formed no guarantee that he actually got it. Then when the first process started, the weight of the grain passed to the first process should be recorded, and then the weight of each subsequent extracted product should be arrived at in turn, that is, the engineer should know just how much screenings, offal, bran, etc., he made, and finally what amount of finished flour he had obtained. By setting these results against the intake, a percentage was readily obtained which should be comparable with a known standard basis.

It might be argued that this labour of weighing would interfere with the general work of manufacture, but the whole of the weighing was now being done automatically at speeds far in advance of what was required by the mill engineer to-day and the weights were automatically recorded and printed; even the finished flour was automatically sacked off and a record shown. From this it would be seen that with the use of a well-designed and practically tested weighing system, the engineer had a continuous record before him whereby he could state absolutely the efficiency of his machinery and, to a great extent, the efficiency of the raw material he was operating on, and the writer did not quite see how this could be done in any other way.

Mr. CREAK wrote, in reply to Dr. Hele-Shaw (page 1042), that the object of the wheat distributor described and illustrated on pages 1022 to 1025 was to divert the stream of grain as it entered the top of the silo or bin, so as to throw the heavier berries to the sides of the bin, leaving the lighter grains to settle in the centre of the bin. When emptying the bin, it was well known that when the slide at the bottom of the hopper was opened, the column of grain immediately above the opening in the hopper bottom tended to flow away. To fill up the place of this column of grain as it moved downwards towards the outlet, the heavy grains that had been deposited near the sides of the bin crowded more quickly and effectively to take the place of the moving centre column than did the lighter grains lying nearer, with the result that the light and heavier grains intermingled near the centre column and passed out together.

If, on the other hand, the stream of wheat poured into the bin directly and without deflection, as indicated in the right-hand bin of Fig. 31 (page 1023), then the heavy grains settled near the centre column of grain, whilst the lighter grains lay nearer the sides of the bin. When the slide at the hopper outlet was pulled open, the heavy grains lying near the moving centre column were all ready to flow out, and by their greater weight kept back the lighter grains until all the heavier grains had been discharged. This action was indicated by the arrows in Fig. 33, as also by the diagrams giving weights per bushel of wheat delivered at different stages of emptiness of bins fitted respectively with and without the distributor (page 1026).

The mechanical arrangements of the free swinging plansifter appeared to be an adaptation of the vibromotor motion invented in 1892 by Mr. W. Worby Beaumont (page 1045), but it differed from the arrangements described in the specification in that the point of suspension of the crank carrying the crank-pin at one end and the counterweight at the other was situated at the centre of rotation located between the crank-pin, which took hold of the plansifter frame at its centre of gravity, and the balance weight. This arrangement had the effect of setting up the truly circular swing of the plansifter immediately the vertical driving shaft began to rotate. This was a point of considerable importance, as the free dressing qualities of the plansifter were closely connected with the true swing of the machine. In the vibromotor arrangements, illustrated in the patent specification, the crank and balance weight were suspended by a flexible connection from a point coincident with the axis of the vertical crank-pin and not from the centre of rotation.

In regard to Mr. George Briddon's remarks (page 1045), bearing in mind the title of the Paper, namely, "Modern Flour-Mill Machinery," the author considered it best to explain the leading

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developments as fully as possible, stating impartially the advantages and disadvantages, and leaving individual opinions to come out in the discussion. The question of the ability of the country mill to hold its own did not really come within the scope of the Paper. That the modern tendency was to locate new mills at the ports could not be denied, but the author was in complete agreement with Mr. Briddon that there were many inland flour-mills which were sufficiently well situated to be able to compete successfully with the up-to-date port mill. Among the determining factors, in addition to those mentioned by Mr. Briddon, were cheap fuel, cheap transit charges, especially by canal, and low local rate charges. Further, it was the author's opinion that road motor traction was destined to assist very materially the inland flour-mill.

With regard to the point raised by Mr. Briddon as to the visibility of the sieve in the two types of purifier illustrated on Fig. 14, Plate 27, and Fig. 17, Plate 28, in the author's opinion the type shown on Fig. 14, Plate 27, gave the clearer view of the sieve. This point was made more evident in the cross-sectional view, Fig. 15 (page 1012). The absence of the settling chambers over the sieve gave a smaller overall height, whilst the large glass doors, inclined towards the centre of the machine, did undoubtedly give a freer view of the sieve.

In reply to Mr. Gardiner Mitchell's remarks (page 1049) on the removal of dust from the wheat mixture, this was effected by aspiration in contradistinction to blowing currents in all modern wheat-cleaning machines, because in every case a settling-box intervened between the aspirated wheat stream and the fan, to drop out automatically the heavier screenings. Were a blowing current used, difficulty would arise in getting the screenings out of the settling chambers, as these would be under pressure and not under suction, as was the case with aspiration. Then, again, joints had to be much more carefully made where blowing currents were used.

As touching the action of the wheat berries in the indented cylinders for the extraction of cockle, it was quite true, as Mr. Mitchell contended, that the larger wheat berries did not enter the indents, but on the other hand the smaller berries did enter, to a certain extent, usually end on, but these rolled out when they got but a little way up the rising side of the revolving cylinder. With regard to the cockle-extracting band illustrated in Figs. 3 and 4 (pages 1000–1), the upkeep of the machine would be greater than that of a line of cockle cylinders. On the matter of power, however, this was so small, even in the case of the band, as to be almost negligible. There would probably be some saving in space to be gained by the adoption of the band machine.

The automatic weigher mentioned on page 1021 was provided with a self-emptying scale-pan at one end of the beam. The bottom of the pan was hoppered on two sides, one of these sides being in the form of a free-swinging door. This was swung to by a counterweight and locked by a suitable catch. When ready to take a weighing, the wheat from a receiving hopper above flowed into the pan in a thick stream. Assuming the capacity of the weigher to be 2 tons per tip, when the pan had received somewhere near its required 2 tons it was partially weighed down. This movement of the scale-pan cut down the stream of wheat flowing into the pan to a thin trickle. By this means accurate weighing was obtained, and the minimum weight of wheat was required to give the beam the necessary draught to cause the final movement or drop of the pan. This final drop cut off the trickle of wheat, and at the same time released the free-swinging door by an arrangement of levers and toggle-joint, and the 2-ton weighing was discharged into a hopper below. The scale-pan, being relieved of its weighing, rose briskly, and in so doing closed the door in the bottom of the pan and opened the valve in the wheat-hopper above the weigher, and the operation repeated itself so long as there was wheat in the hopper above to feed it. By the term "tips" in reference to the above machine, the author referred to "weighings."

With regard to hoppered bottoms for silos, the question of loss of storage space when hoppering such large silos as 30 feet in diameter became a serious consideration, as well as that of the cost. Undoubtedly the hoppered silo was the best from a working point of view, as the author stated at the end of the paragraph on page 1021. It was absolutely necessary to make arrangements for turning the grain over from one silo to another as suggested by

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Mr. Mitchell, and this was provided for in all the silos with which the author had been connected.

In the matter of the pneumatic elevating and conveying of grain, the author agreed with Mr. Simon (page 1052) that this was a likely field for experimental investigation, as the system had so many points in its favour when compared with bucket elevators and conveyors, which necessarily ran in straight lines. The question of the power required to drive individual machines had been very closely investigated by Mr. Simon, and much careful experimenting had been carried out by him, but as the machines had to run together as a complete mill, and individual driving offered no advantages, it was generally sufficient to calculate the power of the machines running as a complete mill. In practice it was found that, averaging the results obtained in mills of varying capacity, the roller-mill plant required 10 h.p. per sack of flour produced per hour, and for the wheat-preparing plant 3 h.p. per sack. With the increasing use of electric motors as prime movers, it became more necessary to determine with exactitude the powers taken by each machine; nevertheless, the author would always advocate a liberal margin in the power of the prime movers, because a miller always tried to get, and generally succeeded in getting, a larger output from his mill than its rated capacity.

When dealing with the question of plansifter versus centrifugal, Mr. Simon had said that the choice of the individual miller was to a large extent a matter of fashion. Would it not be nearer the mark to say it was a matter of prejudice ? In the author's opinion, the plansifter experienced a serious set-back when first introduced into this country some twenty years ago. It must be admitted by all that in its then state of development it was not a success, and was practically withdrawn from the market. The machine as manufactured to-day was, one might say, mechanically perfect, but it had to live down the bad reputation of its predecessor. Another point that militated against its ready adoption in this country was the tendency to consider the plansifter as merely taking the place of so many centrifugals, whereas it was necessary to diagram the whole mill and clothe the machines specially to suit plansifter dressing. This fact was frequently overlooked.

In reply to Mr. Gilbert C. Vyle (page 1056), the items covered by the figure of 0·4*d.* per Board of Trade unit for electric current were stated in the author's reply (page 1043) to the President's remarks. From Mr. Vyle's comments on rope drives, one would gather that trouble was eventually experienced with this form of transmission. From an intimate and extended acquaintance with rope-driven flour-mills of varying capacities, both large and small, the author would assure Mr. Vyle that no difficulty was experienced. For one thing the ropes never gave out at the same time, and it was a simple matter to note the gradual wear of the ropes and to replace defective ones at the week-end stoppage. Undoubtedly the recording watt-meter was a useful tell-tale, but, taking everything into consideration, the author would hesitate to recommend the substitution of electric driving for a good rope-drive at a cost for current exceeding 0·4*d.* per Board of Trade unit, and even at that figure the circumstances of each individual case needed very careful study to ensure an annual saving in working expenses to justify the change.

The author was in complete accord with Mr. Vyle in his remarks as to the importance of weighing the produce of the mill in its various stages. Of course this was all done automatically in every modern mill, excepting the weighing of the sacks of finished flour, bran and offals. True it was that some mills had installed automatic weighers to deal with the sacks of finished products, but this was a difficult operation to carry out successfully on an automatic machine, and this application was by no means universally adopted. No doubt the difficulties now met with in this class of automatic apparatus would eventually be overcome. The records of the various automatic weighers determined for the miller his loss of weight due to the abstraction of seeds, bits of straw, dirt and refuse, his gain of weight due to water absorbed in the washing and conditioning process and so on. Very careful records were kept of the day's grinding to see that the weight of finished products turned out in a given time agreed with the weight of wheat fed in during the same period, when the necessary allowances and adjustments had been made.

The Institution of Mechanical Engineers.

PROCEEDINGS.

20th November 1913.

An Ordinary General Meeting was held in the Memorial Hall, Manchester, on Thursday, 20th November 1913, at Half-past Seven o'clock p.m.; Sir H. Frederick Donaldson, K.C.B., President, in the Chair.

The President remarked, on taking the Chair, that the Meeting was a reversion to a system which used to be in force in years gone by, and, as members of the Institution of Mechanical Engineers, he thought they had to note a little change on what took place in those days. It was his great privilege to welcome to this Meeting the members of the Manchester Association of Engineers, The Manchester Association of Students of the Institution of Civil Engineers, The Manchester Local Section of the Institution of Electrical Engineers, The Manchester Geological and Mining Society, the Municipal School of Technology, and the Manchester University Engineering Society. He did not propose to detain them, but at once to ask Professor Ripper to read his most instructive Paper.

The following Paper was read in abstract and partly discussed:—

"Cutting Power of Lathe Turning Tools"; by Professor William Ripper, D.Eng., D.Sc., *Member*, Dean of the Faculty of Applied Science, and G. W. Burley; of the University of Sheffield.

The Meeting was adjourned at Ten o'clock. The attendance was 138 Members and 128 Visitors.

The Institution of Mechanical Engineers.

PROCEEDINGS.

21st November 1913.

The Adjourned General Meeting was held at the Institution on Friday, 21st November 1913, at Eight o'clock p.m.; Sir H. Frederick Donaldson, K.C.B., President, in the Chair.

The Minutes of the previous October Meeting were read and confirmed.

The **President** announced that the following three Transferences had been made by the Council:—

Associate Members to Members.

Barker, Laurence Checkley,	Bristol.
Bressey, Cyril Edward,	Lagos.
Percy, Harry Leonard,	Colombo.

The following Paper was read in abstract, and the discussion was resumed from the preceding Meeting in Manchester:—

"Cutting Power of Lathe Turning Tools"; by Professor **William Ripper**, D.Eng., D.Sc., *Member*, Dean of the Faculty of Applied Science, and **G. W. Burley**; of the University of Sheffield.

The Meeting terminated at Ten o'clock. The attendance was 106 Members and 48 Visitors.

CUTTING POWER OF LATHE TURNING TOOLS.

(Being an Account of Experiments made in the Machine-Tool Laboratory of the University of Sheffield.)

By Professor WILLIAM RIPPER, D.Eng., D.Sc., *Member*,
Dean of the Faculty of Applied Science,
and G. W. BURLEY; of the University of Sheffield.

Object of the Tests.

The question of the definite measure of the output of work, or of the removal of material, of which lathe-tools are capable, is one about which there is very little information readily available; and it was for the purpose of determining the behaviour of cutting tools over a fairly wide series of working conditions, and of deducing therefrom some practical results, that the following experiments have been undertaken.

The object of the tests includes the determination of the way in which the output, of both high-speed and ordinary carbon-steel tools, is affected by such elements as the speed of cutting, the depth of the cut, the feed of the tool per revolution of the work, the shape of the nose of the tool, and the physical properties of the metal upon which the cutting tool is acting. In particular, the question of the association of a high speed and a light cut versus the association of a low speed and a heavy cut, received consideration with a view to finding the relation of these two factors to maximum output.

Further points were to determine whether the above relationships are on the whole as regular and uniform as they may reasonably be expected to be when the conditions of the tests are approximately uniform; or whether they are irregular and erratic as they have sometimes been reported to be; also whether the usual workshop notions as to the durability of tools at varying cutting speeds are confirmed by careful experiment.

For example, in Papers read before the Iron and Steel Institute by Mr. Edward G. Herbert, B.Sc.,* on "The Cutting Properties of Tool Steel," experiments were described, and curves of durability at varying cutting speeds were given, from which it was concluded that the general characteristics of the performance of tool-steels are:—

A very low durability at the lower cutting speeds;
An increase of durability as the cutting speed increases;
A maximum durability at a cutting speed of 50 to 80 feet per minute; and
A decline of durability to a very low value as the speed is further increased.†

These results were obtained in a specially designed "tool-steel testing machine," having a cutting tool applied at the bottom end of a small rotating tube placed vertically above the cutting tool. The tube was of steel, $\frac{3}{4}$ inch diameter and $\frac{5}{8}$ inch bore, and was pressed down against a dead stop by a heavy weight. The cutting tool, which pressed against the bottom edge of the tube, was carried on the end of a lever, which was so adjusted that a given pressure could be imparted to it in order to regulate the amount of the cut to be obtained. The amount of wear on the cutting edge was measured by the deflection of the lever. A curve of performance was drawn automatically as the experiments proceeded, but this curve was not a time-speed curve, but a length-of-tube by speed curve.

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* Journal, Iron and Steel Inst., 1910, page 206; and 1912, page 358.

† "The Influence of Heat on Hardened Tool-Steels," Journal, Iron and Steel Inst., 1912, pages 358–9.

The results obtained by Mr. Herbert were so different from the usually accepted ideas as to the behaviour of tool-steel working under ordinary cutting conditions (as distinguished from scraping or finishing a surface) that it seemed desirable to determine by experiment, under ordinary conditions, how far the above characteristics, obtained with the Herbert tool-testing machine, really corresponded with the conditions found in ordinary lathe-tool practice, and how far they were peculiar to the special circumstances and method of the test as described in Mr. Herbert's Paper.

It may be stated at once that many experiments were made, and much time spent in endeavouring to find a tool-steel, and a condition of working it, which would show either "a very low durability at the lower cutting speed," or "an increase of durability as the cutting speed increases," or a maximum durability other than at a minimum cutting speed, but entirely without success. The result in every case, without exception, was that the durability of the tool was some function of the reciprocal of the cutting speed; and that, in fact, under all the conditions of the authors' tests, the slower the cutting speed the greater the durability of the tool, and, conversely, the higher the cutting speed the lower the durability, the ratio being expressed by formulæ of a simple form deduced from the experiments with lathe-tools hereinafter described.

The machine invented by Mr. Herbert for testing tool-steels is a very ingenious one, and the experiments described by him were very carefully made, but the results obtained do not, in the authors' opinion, appear to be directly comparable with those usually found during the operation of cutting with ordinary lathe-tools, as distinguished from scraping or finishing a surface. It is possible that Mr. Herbert's results would be found of much value when applied to the durability of milling cutters and reamers and similar tools, and a continuation of this research to determine their application to this class of tools is now in hand. The following is a description of the details of the experiments made:—

TYPES OF TOOLS TESTED.

Two classes of tools were tested, namely, ordinary carbon-steel tools and high-speed steel tools.

By the term carbon-steel tools is meant tools made of ordinary tool-steel as distinguished from those made of self-hardening steels and high-speed steels. The characteristic composition of carbon tool-steel is approximately as follows:—

	Per cent.
Carbon	1·3
Silicon	0·12
Manganese	0·2
Sulphur	0·03
Phosphorus	0·015

Its characteristic behaviour as a cutting tool is that it possesses the property of becoming hardened by heating and quenching, and of retaining its hardness while working as a cutting tool up to a temperature at the nose of about 300° C., beyond which temperature the hardness disappears and the cutting edge of the tool softens.

By the addition, however, of certain materials in the manufacture of carbon tool-steel, the temperature of stability of the hardness, or, in other words, the temperature at which the steel softens or breaks down, due to the heat generated by friction at the nose of the tool, is raised, and the ability of the tool to cut is greatly improved. The first step in this direction was made by the addition of tungsten to the ordinary carbon-steels forming the celebrated Mushet or self-hardening steel, and raising the temperature of the softening point to about 400° C. Later, by the further addition of chromium, and afterwards of vanadium, we have the still more celebrated high-speed steels with a considerably increased temperature of stability of their hardening properties, the steel retaining its cutting edge for a short time, even at a visible red heat.

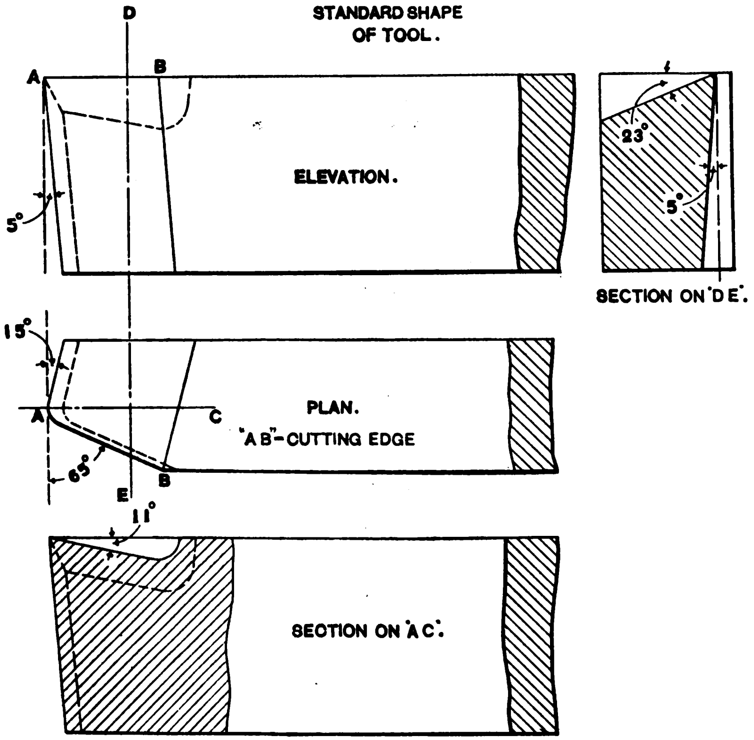
The increased working temperature of the steel thus produced by the addition of these metals to ordinary carbon-steels has resulted in increasing enormously their capacity for output by increasing the possible cutting speeds, as well as the possible depths and feeds of cuts taken.

I.

Carbon-Steel Tool Tests.

The ordinary carbon-steel tools tested were made from ¾-inch by ½-inch bars, and 6 inches long, and the tools were ten in number.

Fig. 1.



The shape of the tool-nose adopted as the standard shape for the first set of tests was that indicated in Fig. 1, in which an elevation and plan of the nose are shown. The side cutting edge AB is horizontal and inclined at an angle of 25° to the length of the tool, so that when the tool is in its correct position in the slide-rest, the cutting edge makes an angle of 65° to the axis of the work or test-bar between the centres. The end of the tool is inclined at an angle of 75° to the length. The angles of the tools were as follows:—

Top rake—front = 11°. Front or heel clearance = 5°.
Side rake = 23°. Side clearance = 5°.

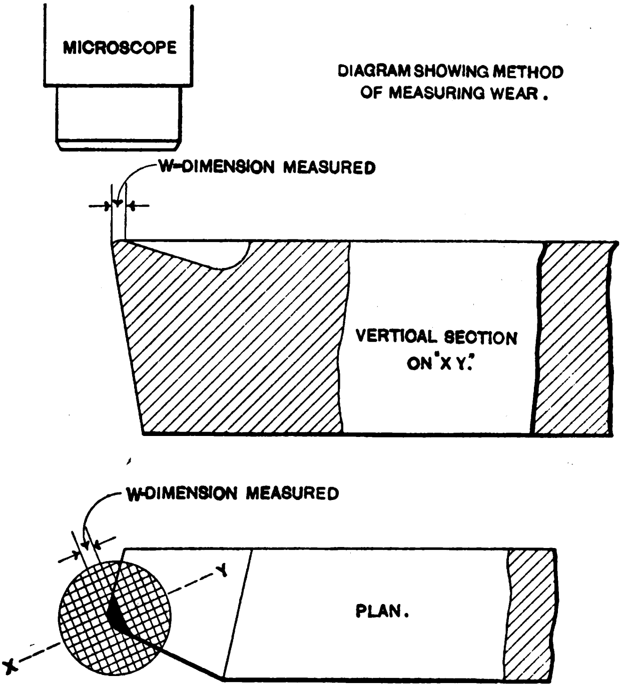
These angles were ground exactly, on every tool tested, on a Universal tool grinder, so that the question of the angles of the tool did not affect the comparative results, in the first part of the research.

Test-Bars.—The test-bars on which the carbon-tools were tested were steel bars of various chemical compositions and physical properties, four different classes being worked upon, marked W, X, Y, and Z, and varying in composition from 0·23 per cent. of carbon to 0·82 per cent. of carbon. The bars were made from ingots cast in the metallurgical laboratories of the University of Sheffield, under the direction and with the kind co-operation of Dr. J. O. Arnold, F.R.S., and were about 2 feet 6 inches long and 6 inches in diameter when finished, after hammering and annealing.

Test Lathe.—The tests were made in a 6-foot by 6-inch centre Lang lathe fitted with a variable-speed gear, so that fine adjustments of cutting speed could be obtained through a fairly wide range, this range being from 10 feet per minute to 300 feet per minute on a diameter of 6 inches.

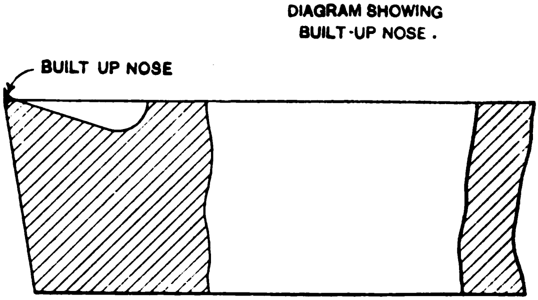
Measure of Standard of Bluntness of Tool.—The method adopted in testing these tools involved the microscopic examination of the cutting edge, this being found to be the only possible method of establishing a standard of measure of the working life of the tool. Each tool was allowed to cut for a certain number of minutes, at a selected speed with a selected area of cut (depth of cut by feed of tool per revolution of test-bar), at the end of which time the tool was removed from the tool-holder and then placed under the microscope for the purpose of examining the cutting edge to see to what extent the edge had been dulled or blunted. A micrometer screen in the eye-piece of the microscope enabled the amount of the blunting to be measured. The dimension which was measured in each case is indicated in Fig. 2. The degree of blunting, as it may be termed, was not in any case of a uniform width along the nose of the tool, but the width actually measured (that is, the dimension W) was the greatest width that could be found under the microscope in each case. To determine the limiting duration of the test, that is, the duration to produce unit bluntness, three and sometimes four tests and microscopic examinations were made on each tool, at one constant cutting speed and area of cut, the tool being measured for bluntness after each test, and then replaced in exactly the same condition and position in which it was when

Fig. 2.


MICROSCOPE
DIAGRAM SHOWING METHOD OF MEASURING WEAR.
W-DIMENSION MEASURED
VERTICAL SECTION ON "X Y."
W-DIMENSION MEASURED
X
X
PLAN.

removed from the lathe. Thus, the values of W corresponding to three or four durations were obtained, and from these results curves were plotted, and the duration of the test which corresponded to what was adopted as the "unit" or "standard wear" was found by measurement from the curves. In no other way was it found possible or practicable to obtain this duration satisfactorily. The "unit" or "standard wear" adopted finally was 0·005 inch, as this was found to be about the average amount of blunting which is usually allowed on the cutting edge of a carbon-cutting-tool in practice before it is re-sharpened. In the plan, Fig. 2, the squares are ruled on the micrometer screen to the standard width, and W is shown equal to 1·9 units or 1·9 by 0·005, that is, 0·0095 inch.

Fig. 3.



This method of testing the durability of tools was finally adopted after repeated failures to find a method of determining a standard breaking-down point for the tool. One difficulty arose from the almost invariable tendency of the tool to build up a new nose, or new cutting edge, on the point of the original one, as shown in Fig. 3. This new nose appeared to form a protecting cutting edge for the tool and to prolong indefinitely the life of the tool; but on examining the matter more closely it was found that, although a sharp nose was being presented to the work, a cumulative blunting action was going on all the time on the cutting edge of the tool below the false nose. As soon as this blunting effect was discovered, it became an easy and straightforward task to find a measure of bluntness of the given tool for any given duration of cutting speed and dimension of cut. The false nose is formed by particles scraped from the work, which form themselves into a solid mass between the chip, the work, and the nose of the tool, the false nose becoming larger as the tool itself becomes blunter; the blunting of the tool itself is due apparently to the pressure transmitted to the cutting edge of the tool through the superimposed material. The built-up nose had, of course, to be removed before a microscopic examination of the bluntness of the cutting edge could be made.

Relation between Wear of Tool and Duration of Test.

Representative curves showing the relation between the wear of the cutting edge (or the above dimension W) and the duration of the test are given in Figs. 4–11 (pages 1076–9). Each set of curves constituting the whole figure represents experiments made with a definite area of cut (depth of cut by feed of the tool per revolution of the test-bar). Each curve represents experiments made at a definite cutting speed. The areas of cut and test-bar designation numbers for which these Figs. 4–11 stand are as follows:—

		inch	inch		
Fig. 4.—Area of Cut	=	0·020	× $\frac{1}{36}$ . .	Bar W	(Mild Steel)
„ 5.— „ „	=	0·120	× $\frac{1}{36}$ . .	„	(„ „)
„ 6.— „ „	=	0·020	× $\frac{1}{36}$ . .	Bar X	(Medium Steel)
„ 7.— „ „	=	0·120	× $\frac{1}{36}$ . .	„	(„ „)
„ 8.— „ „	=	0·020	× $\frac{1}{36}$ . .	Bar Y	(Hard Steel)
„ 9.— „ „	=	0·120	× $\frac{1}{36}$ . .	„	(„ „)
„ 10.— „ „	=	0·020	× $\frac{1}{36}$ . .	Bar Z	(Very Hard Steel)
„ 11.— „ „	=	0·120	× $\frac{1}{36}$ . .	„	(„ „ „)

The tensile and compression strengths and chemical compositions of the bars are given in Appendix II (*a*) and III (*a*) (pages 1135–6).

The following is a complete list of all the areas of cut used in the tests with carbon-steel tools, these being used on each of the four classes of test-bar:—

(*continued on page* 1080.)

FIG. 4.

RELATION BETWEEN WEAR AND TEST-DURATION.

DEPTH: 0·020" FEED: $\frac{1''}{36}$ MILD-STEEL BAR.

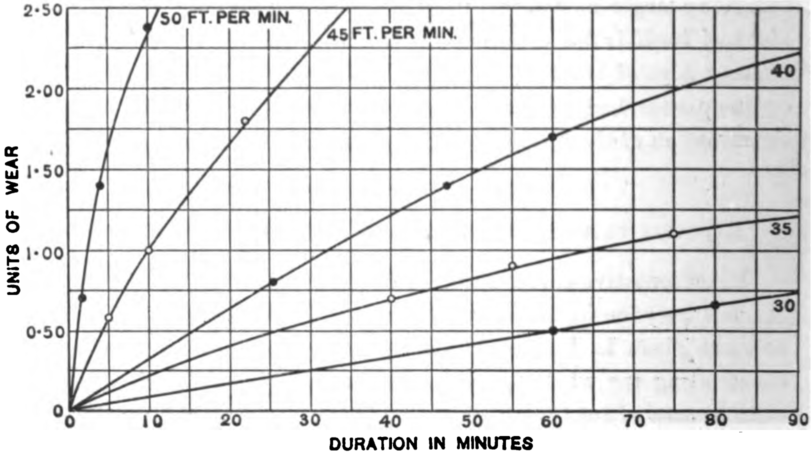


FIG. 5.

RELATION BETWEEN WEAR AND TEST-DURATION.

DEPTH: 0·120" FEED: $\frac{1''}{36}$ MILD-STEEL BAR.

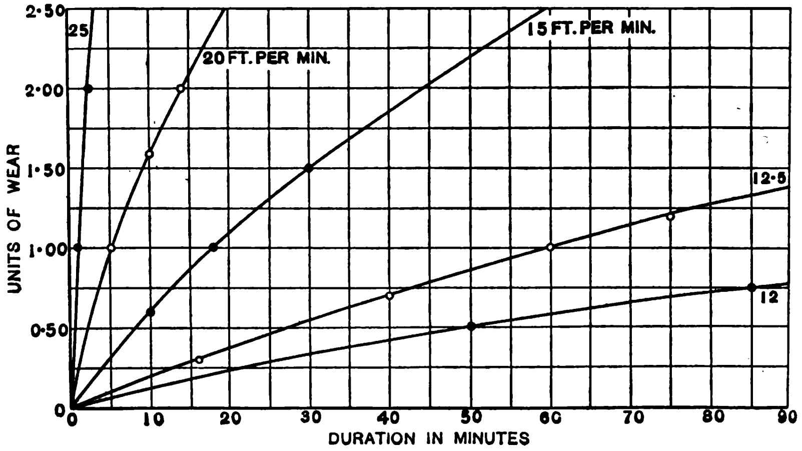


Fig. 6.

RELATION BETWEEN WEAR AND TEST-DURATION.

DEPTH: 0·020" FEED: $\frac{1''}{36}$ MEDIUM-STEEL BAR.

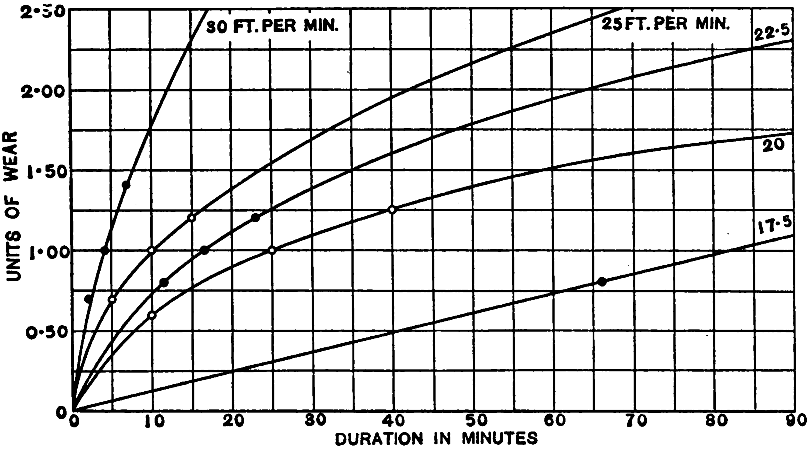


Fig. 7.

RELATION BETWEEN WEAR AND TEST-DURATION.

DEPTH: 0·120" FEED: $\frac{1''}{36}$ MEDIUM-STEEL BAR.

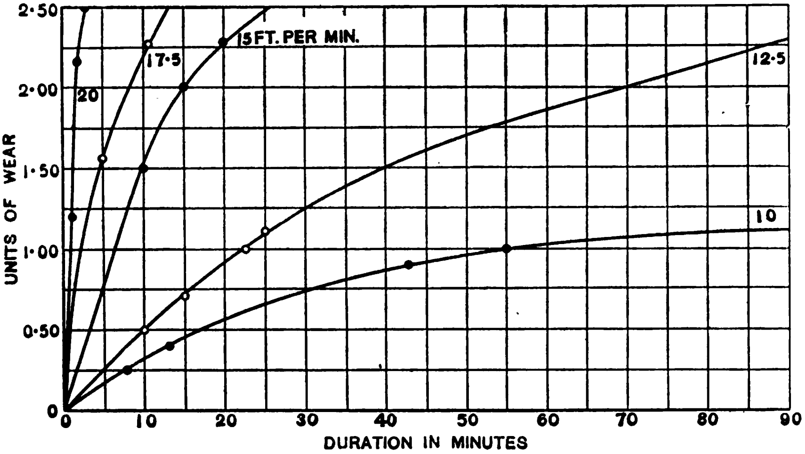


FIG. 8.

RELATION BETWEEN WEAR AND TEST-DURATION.

DEPTH: 0·020″ FEED $\frac{1}{36}$″ HARD-STEEL BAR.

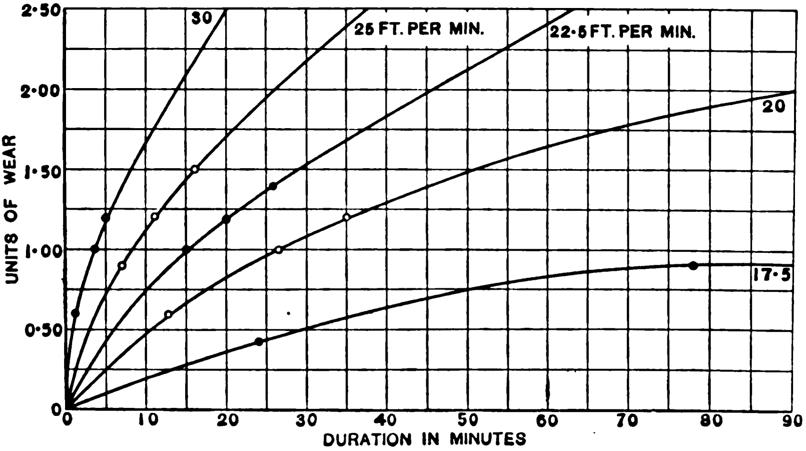


FIG. 9.

RELATION BETWEEN WEAR AND TEST-DURATION.

DEPTH: 0·120″ FEED: $\frac{1}{36}$″ HARD-STEEL BAR.

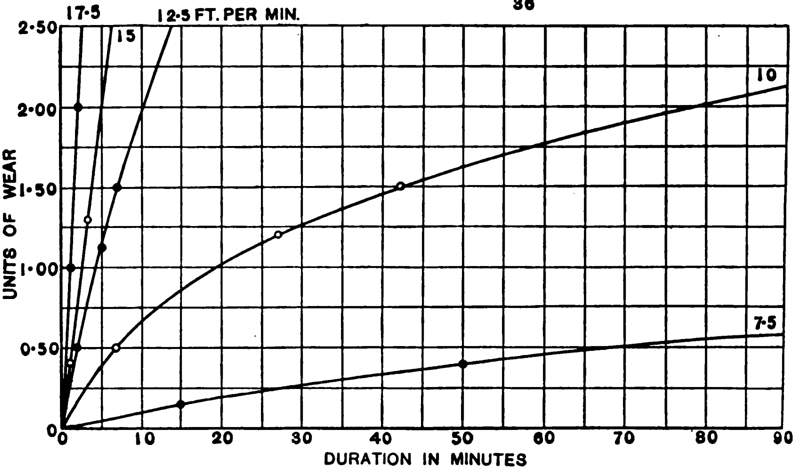


Fig. 10.

RELATION BETWEEN WEAR AND TEST-DURATION.

DEPTH: 0·020" FEED: $\frac{1''}{36}$ VERY-HARD-STEEL BAR.

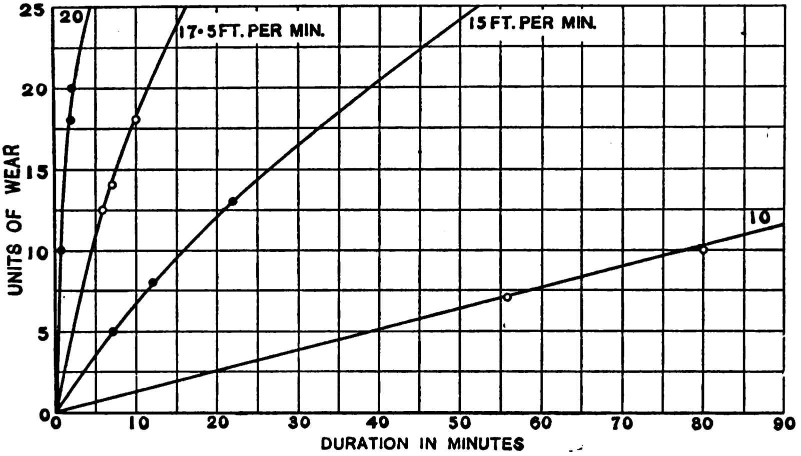
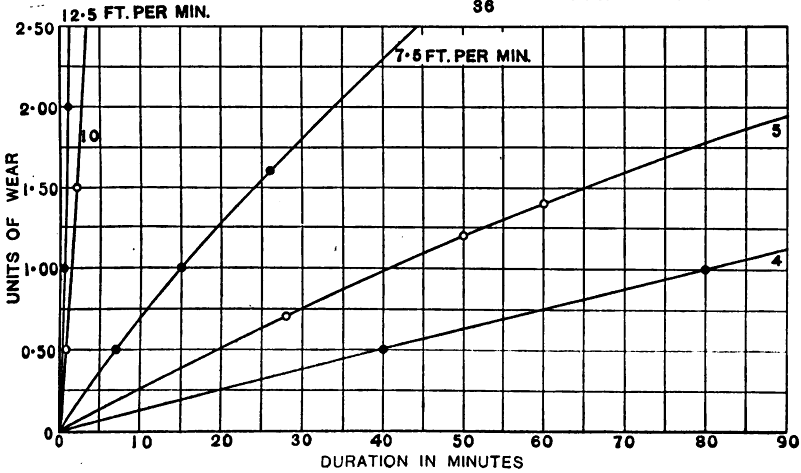


Fig. 11.

RELATION BETWEEN WEAR AND TEST-DURATION.

DEPTH: 0·120" FEED: $\frac{1''}{36}$ VERY-HARD-STEEL BAR.



Depth of Cut.		Feed per Revolution.			
Inch 0·020	×	Inch $\frac{1}{12}$	Inch $\frac{1}{24}$	Inch $\frac{1}{36}$	Inch $\frac{1}{48}$
0·040	×	,,	,,	,,	,,
0·080	×	,,	,,	,,	,,
0·120	×	,,	,,	,,	,,

An important limitation to the size of cut is the heavy cost of material used up during the tests; but although the areas of cut taken are small, they include the conditions under which a very large proportion of the machine-tool work of the world is done.

Altogether about 320 cutting-speed and cut-area combinations were taken, involving the making of about 1,000 individual micro-examinations of the cutting edges of the tools.

In all cases the work has been run dry, that is, without lubrication at the cutting edge of the tool.

CUTTING SPEEDS TO PRODUCE STANDARD BLUNTNESS.

From each set of wear-duration curves, Figs. 4–11, the durations for standard or unit bluntness at the selected cutting speeds were measured, and these were utilized to form speed-duration curves such as are shown in Figs. 12–15. Thus on Fig. 4 (page 1076) the dots or points indicate the results of actual measurements of wear for given cutting speeds; then, by noting the points of intersection of the horizontal line of unit bluntness, with the respective curves, the corresponding durations are obtained. These results, arranged as a separate figure, form the curves of duration for unit or standard wear at given cutting speeds. Each curve of this set corresponds to one set or batch of curves of the wear-duration variety. These four figures contain representative curves for each of the four test-bars as follows (the areas of cut being as given):—

FIG. 12.—Bar W . Areas of Cut = 0·02, 0·04, 0·08, and 0·12 × $\frac{1}{24}$ in. feed.
,, 13.— ,, X . ,, ,, = ,, ,, ,, ,, ,, × ,,
,, 14.— ,, Y . ,, ,, = ,, ,, ,, ,, ,, × ,,
,, 15.— ,, Z . ,, ,, = ,, ,, ,, ,, ,, × ,,

Fig. 12.

CUTTING SPEED AND DURATION TO PRODUCE STANDARD BLUNTNESS.
CARBON TOOLS ON
MILD STEEL.

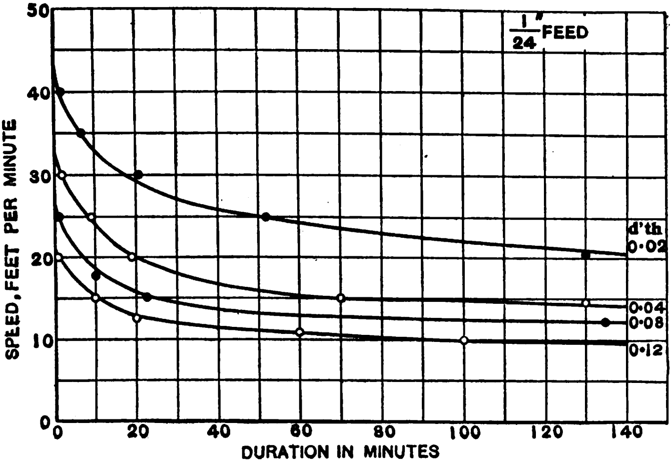


Fig. 13.

CUTTING SPEED AND DURATION TO PRODUCE STANDARD BLUNTNESS.
CARBON TOOLS ON
MEDIUM STEEL.

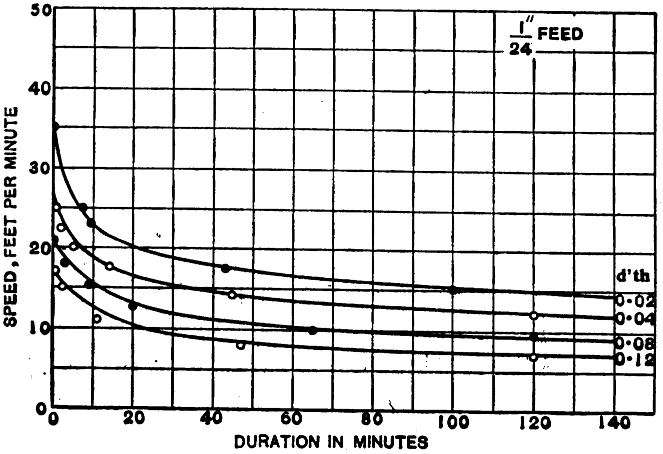


Fig. 14.

CUTTING SPEED AND DURATION TO PRODUCE STANDARD BLUNTNESS.
CARBON TOOLS ON
HARD STEEL.

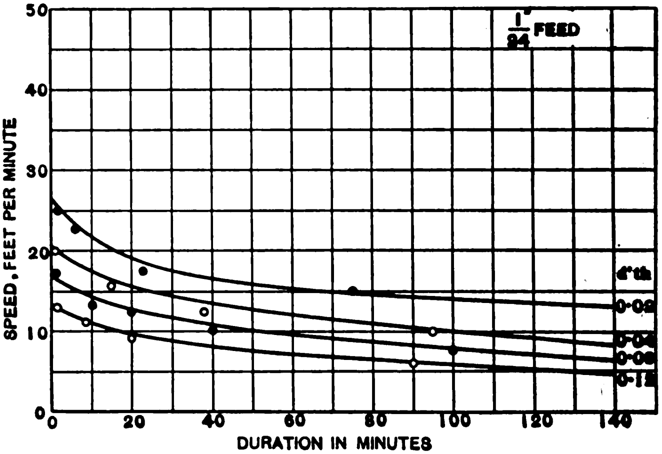
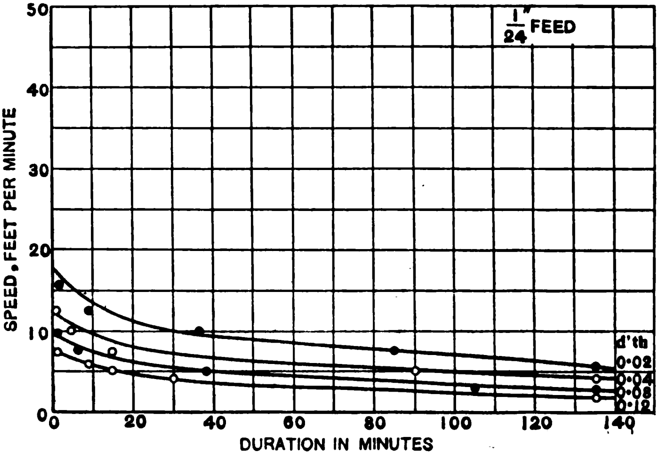


Fig. 15.

CUTTING SPEED AND DURATION TO PRODUCE STANDARD BLUNTNESS.
CARBON TOOLS ON
VERY HARD STEEL.



These curves, owing to their tendency to become horizontal, seem to indicate that there is a cutting speed for each area of cut and each test-bar, beyond which the tool would last more or less indefinitely under the given conditions; in other words, it would cut efficiently for many hours, but if this speed is exceeded by from 15 to 25 per cent. the conditions are such that the tool will fail somewhat rapidly.

EFFECT OF HARDNESS OF BAR ON CUTTING SPEED.

Comparisons between the four test-bars in regard to the relation between the cutting speed and the cutting time are made in Fig. 16 (page 1084). The area of cut selected is 0·040 inch by $\frac{1}{24}$ inch, and the tools are run at a given speed until they reach standard bluntness. The figure shows that, for any given cutting time the harder the bar the lower the cutting speed, the ratio of the cutting speeds for any given life of the tool being approximately equal to the inverse ratio of the carbon contents of the bars. Thus for an 80 minutes' run the cutting speed, Fig. 16, for the hard bar (C = 0·82) is 5 feet per minute, and the cutting speed for the soft bar (C = 0·23) is 15 feet per minute; that is, the cutting speeds are, roughly, inversely proportional to the carbon contents, as also to the tensile strength. The exact degree in which the cutting speed is affected by the tensile strength of the bar is given later.

It also shows that, for all the bars, the high cutting speeds are associated with the short durations or times of cutting, so that if the cutting speed is increased, the time of cutting required to produce the standard amount of wear is reduced. The relationship between the increase of speed and the reduction of time is not a very simple one, but for cutting times between 10 minutes and 100 minutes the average duration is found to be :—

$$M = \frac{\text{constant}}{S^5} \quad . \quad . \quad . \quad (1)$$

where S = the cutting speed in feet per minute, and M = the time of cutting, in minutes, required to produce the standard amount of wear on the cutting edge of the tool. That is, the duration of cutting is approximately inversely proportional to the

FIG. 16.

EFFECT OF HARDNESS OF BAR ON CUTTING SPEED AND DURATION TO PRODUCE STANDARD BLUNTNESS.

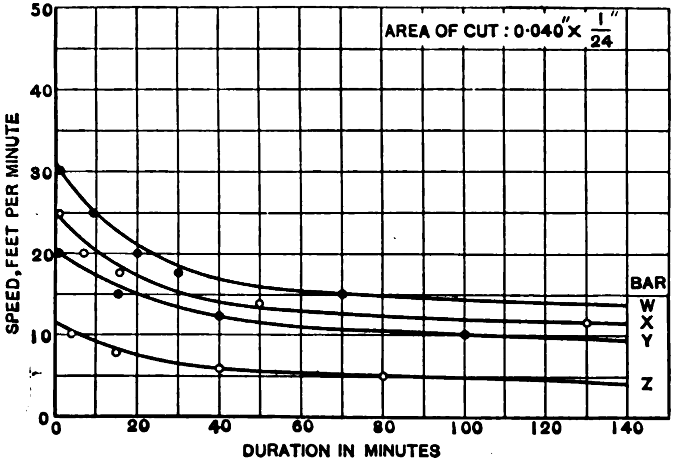
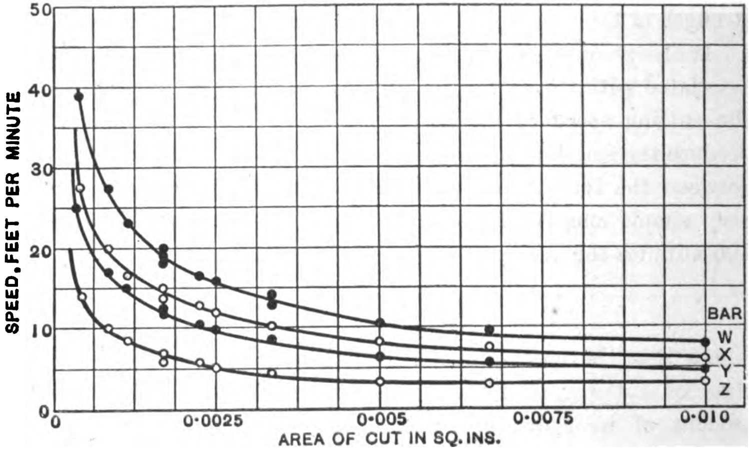


FIG. 17.

RELATION OF CUTTING SPEED TO AREA OF CUT TO PRODUCE STANDARD BLUNTNESS IN 60 MINS. CARBON TOOLS.



fifth power of the cutting speed. The value of the constant depends, of course, upon the test-bar (or the composition and properties of the metal being machined) and the area of cut.

STANDARD TESTS. RELATION OF CUTTING SPEED AND AREA OF CUT TO PRODUCE STANDARD BLUNTNESS IN 60 MINUTES.

To systematize matters it was decided to make a standard test, which should produce a condition of unit bluntness of the cutting edge of the tool after a 60 minutes' run. This unit bluntness in 60 minutes could be obtained in various ways by a series of combinations of speeds and areas of cut. These results were then combined into one curve, as shown in Fig. 17, the upper curve representing such a series for the mild steel test-bar W, and the lower curves representing respectively the other bars of gradually increasing hardness X, Y, Z.

With each given area of cut there is a certain speed which will produce standard bluntness in 60 minutes, this speed having been termed the "associated" cutting speed for the given area of cut. In this series it has not been found necessary or possible to separate the two factors of depth of cut, and feed, which make up the area of cut, because with carbon tools in practice the cuts are comparatively light, and the differences of result produced by changing the ratio of these factors are so small as to be almost negligible. The relation between the area of cut and the associated cutting speed is found to obey approximately the law—

$$AS^2 = \text{a constant} \quad . \quad . \quad . \quad (2)$$

$$\text{or} \quad S = \frac{\text{constant}}{\sqrt{A}} \quad . \quad . \quad . \quad (3)$$

where A = area of cut, and S = cutting speed in feet per minute. The value of the constant depends upon the composition of the bar.

Output Curves.—From the curves, Fig. 17, the speed associated with each area of cut was measured, and with these factors the output, or the number of cubic inches of material removed per hour, was calculated, and the curves, Fig. 18 (page 1087), constructed therefrom.

The ordinates of the curve = area of cut × cutting speed × 12 × 60 = cubic inches turned off per hour.

Effect of Hardness of Test-bar, Speed, and Cut-area on Output.—It will be seen from Fig. 18 that for any given cutting speed with its associated area of cut, to give the tool a life of one hour, the volume of metal removed is greatest with the softest bar and least with the hardest.

It also shows that large output is by no means associated with high cutting speed, but that as the cutting speed is reduced (with, of course, a suitable increase in the area of cut), the output is increased; in other words, a heavy cut is better than a high cutting speed. Thus it will be seen that, for bar W, when the cutting speed is 10 feet per minute, the volume of metal removed per hour is 40 cubic inches when the associated area of cut for this speed is used; whilst when the speed is, say, 20 feet per minute, and the associated area of cut is correspondingly less, the volume removed is only about 21 cubic inches. Hence, as a general law, it may be stated that for maximum tool output, the area of cut employed is a maximum and the associated cutting speed is correspondingly low.

This is also indicated in Fig. 19, which gives the relation between the volume of metal removed in the hour under the standard conditions and the area of cut. It will be seen that the greater the area of cut, accompanied by its appropriate or "associated" cutting speed, the greater the volume of metal removed. In other words, a low cutting-speed and heavy-cut combination is preferable to a high cutting-speed and light-cut combination from the point of view of output.

Fig. 19 shows further that with a fixed area of cut and its accompanying associated speed, the ratio of the output on steels of varying hardness is inversely proportional to the tensile strength of the material being machined.

Relative Hardness of Material as Measured by Tensile Strength.—To determine the relative hardness of the material turned, many methods were tried, but it was ultimately found that the test of

Fig. 18.

EFFECT ON OUTPUT OF INCREASED CUTTING SPEED WITH ACCOMPANYING REDUCED AREA OF CUT.
CARBON TOOLS.

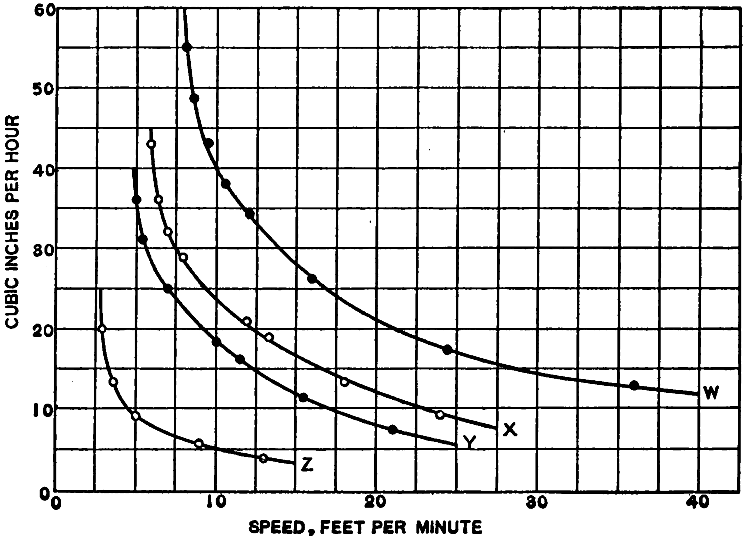


Fig. 19.

EFFECT ON OUTPUT OF INCREASED AREA OF CUT WITH ACCOMPANYING REDUCED CUTTING SPEED.
CARBON TOOLS.

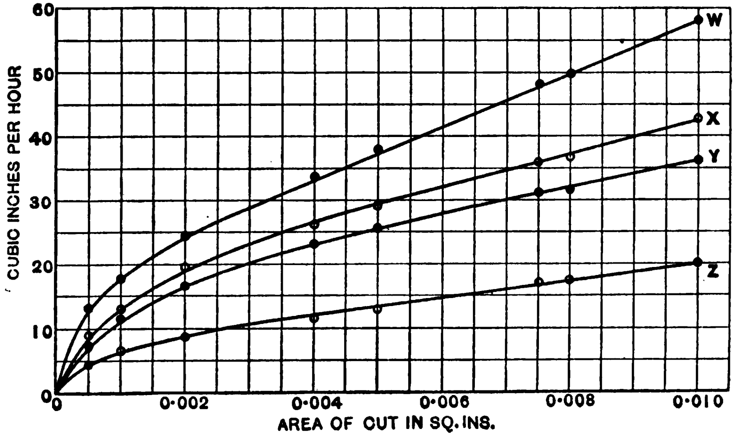


FIG. 20.

RELATION OF STANDARD CUTTING SPEED TO TENSILE STRENGTH FOR VARYING AREAS OF CUT.

CARBON TOOLS.

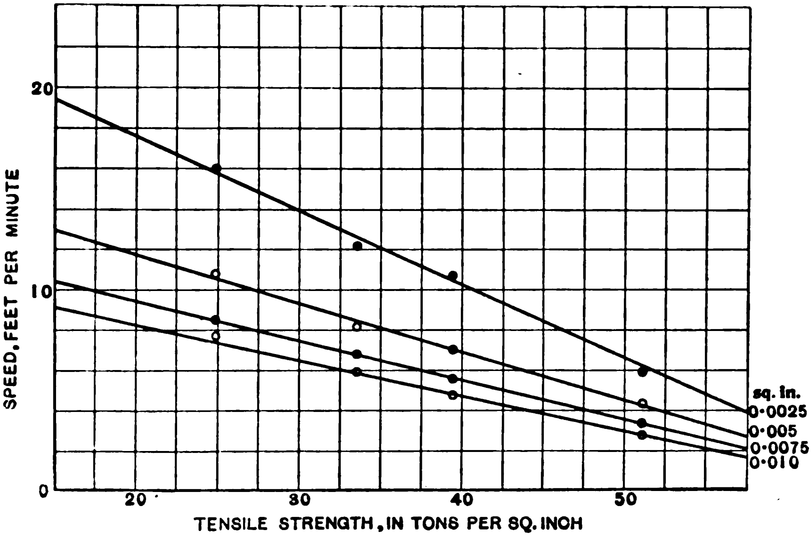


FIG. 21.

PLAN AND ELEVATION OF TOOL WITH LONG CUTTING EDGE "A B".

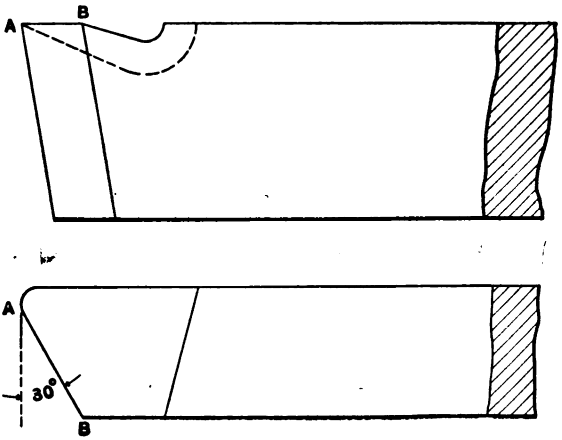


Fig. 22.

DIAGRAM SHOWING EFFECT OF SHAPE OF NOSE UPON LENGTH OF CUTTING EDGE OF TOOL.

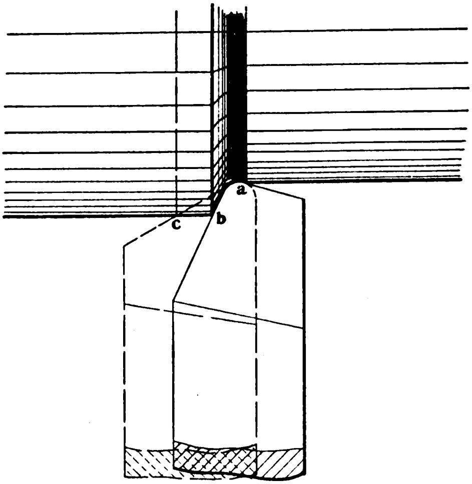
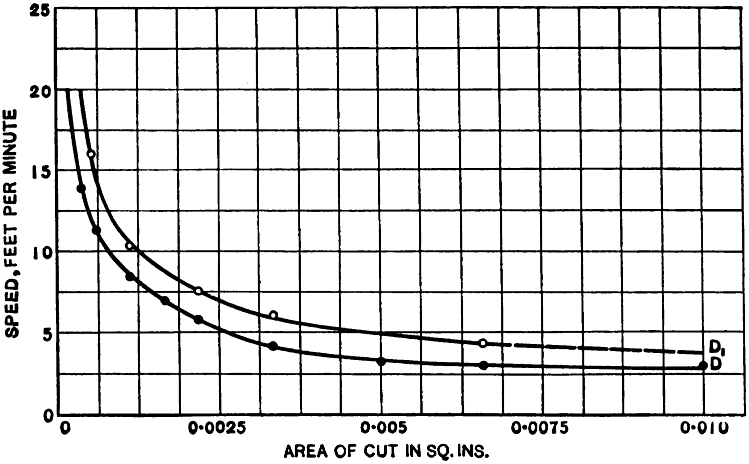


Fig. 23.

CURVES SHOWING EFFECT OF LENGTH OF CUTTING EDGE ON CUTTING SPEED.

CARBON TOOLS.



the tensile strength of the material was the most reliable and conveniently-made test of relative hardness, the hardness being practically directly proportional to the tensile strength. The crushing test of a sample compression piece would seem to be the most reasonable test of hardness of a material, but the comparative hardness determined in this way was as nearly as possible similar to that obtained by comparing the tensile strengths.

Relation between Tensile Strength of Material and Cutting Speed of Tool.—In Fig. 20 (page 1088) is shown the relationship between the tensile strength of the metal being machined, and the associated or working cutting speed for four different areas of cut, the speed and the area of cut being associated to give a standard life of 60 minutes to the tool. The law is a straight-line law, the equation to it being:—

$$S = \frac{(67 - T) \times 0{\cdot}0185}{\sqrt{A}} \quad . \quad . \quad . \quad (4)$$

where S = the associated cutting speed in feet per minute; T = the tensile strength of the metal being machined in tons per square inch; and A = the area of cut in square inches.

Effect of Shape of Nose of Tool on Cutting Speed.—To determine the effect of a change in the shape of the nose of the tool, and in the disposition of the cutting edge with respect to the axis of the test-bar, tools having a shape of nose as represented in Fig. 21 were tested against tools of the shape of Fig. 1 (*see* Fig. 22). The same conditions as to test were adopted in each case. That is, the tools were tested for wear of the cutting edge, with a standard tool life of 60 minutes.

Under these conditions, the relation between the cutting speed and the associated area of cut was determined. This relation is indicated graphically in Fig. 23, the curve D_1 being obtained with the form of tool nose represented in Fig. 21, and the curve D with the original or standard shape of nose, Fig. 1. It will be seen that for each area of cut the associated cutting speed is less for the standard shape of nose, which has a comparatively short cutting edge (*a*, *b*, Fig. 22), than it is for the second shape of nose, which has a longer cutting edge (*a*, *c*, Fig. 22). These speeds have an average ratio of 1 to 1·40, which ratio is also approximately that of the length of the respective cutting edges of the tools in contact with the work.

In other words, for a given depth of cut, the associated cutting speeds of tools for a given amount of wear are directly proportional to the length of the cutting edge of the tool in contact with the work. That is, a proportionately greater output can be obtained with the tool having a longer cutting edge. In all other respects the angles of the tools were the same.

SUMMARY OF CONCLUSIONS.

(1) *From Carbon-Steel Tool Test Results.*

1.—Blunting of the cutting edge develops more rapidly at high speeds than at low speeds, given the same area of cut and the same shape of nose of tool.

2.—Within the limits of the authors' experiments, the durability of carbon-steel tools is in all cases some function of the reciprocal of the cutting speed, in other words, the higher the cutting speed the shorter the durability of the tool, and vice versa.

3.—Assuming a standard amount of bluntness of 0·005 inch, the cutting speed to produce this bluntness is inversely proportional to the fifth root of the duration or life of the tool for durations between 10 and 100 minutes for any given area of cut, or conversely the life of the tool is inversely proportional to the fifth power of the cutting speed. This law does not hold good for durations which are external to these limits.

4.—Within the limits of the authors' experiments, the cutting speed duration curve beyond the point representing a duration of 100 minutes tends to become horizontal, this suggesting that there is, in each case, a definite cutting speed below which the tool would last practically an indefinite length of time.

5.—For a standard tool life of 60 minutes and a standard amount of bluntness of 0·005 inch, as determined by means of the microscope, high cutting speeds are invariably associated with light cuts, and low cutting speeds with heavy cuts.

6.—The associated cutting speed for a given area of cut is not influenced by the manner in which the area of cut is made up—that is, the influence of the depth of the cut upon the associated cutting speed is exactly the same as that of the feed. This applies only to carbon-steel tools with which cuts of small area only are possible; with high-speed steel tools this condition does not apply.

7.—The associated cutting speed is not reduced or increased in the same ratio as the area of cut may be increased or reduced.

8.—The associated cutting speed for any area of cut depends upon the hardness of the metal which is being machined, a high speed being associated with a low degree of hardness or vice versa.

9.—For a given area of cut with its associated cutting speed, the output of the tool acting on steels of various qualities is roughly inversely proportional to the tensile strength of the respective materials being machined.

10.—A tool working at a low speed with its associated area of cut will remove far more material under standard conditions in one hour than one which is working at a high speed with its associated area of cut.

11.—A tool with a long cutting edge has a longer life (under similar conditions of area of cut, cutting speed, and hardness of metal being machined) than one which has a short cutting edge.

II.

High-speed Steel Tool Tests.

The Tools.—The high-speed steel tools which were put under test were made from $\frac{3}{4}$-inch by $\frac{1}{2}$-inch bars, as in the case of the carbon-steel tools, the tools being made about 8 inches in length. The shape of nose adopted for the first set of tests was that used for the corresponding ordinary carbon-steel tool tests, and as illustrated in

Fig. 1 (page 1071). The tools were made of a high grade of high-speed steel, shaped entirely by grinding in a Universal tool grinder—thus dispensing with the necessity of forging—and then hardened according to the directions of the maker. This size and shape of tool were adopted so that the tests would be comparable with those made on the carbon-steel tools.

A further series of tests have since been made to determine the relative effects of area of tool-steel section upon the possible output, as measured by the relative areas of cut which the tools would respectively take, the conditions as to cutting speed being similar, and a series of factors obtained, so that when the output with the given section is known, the output with a tool of any other required section may be obtained by the aid of a factor (*see* page 1114).

The Test Lathe.—The tests were made on the large electrically-driven experimental tool testing lathe (18-inch centres) installed in the machine-tool laboratory of the University of Sheffield, and described in Appendix I (page 1124). (*See* also Plate 36.)

The Test-Bars.—The test-bars used were three in number and of different chemical compositions and physical properties (*see* Appendixes II *b* and III *b*, pages 1135–6). Their approximate original dimensions were :—

Length = 9 feet 6 inches.
Diameter = 1 foot 8 inches.

Their identification letters are A, B, and C, bar A being mild steel, bar B medium steel, and bar C hard steel.

Two of the bars, the mild steel and medium steel bars, were parts of propeller shafts of dismantled ships. The hard bar was especially cast, forged, and annealed for the purpose of the tests.

Test-pieces were cut from each end of the respective bars and tested. The bars were found to be practically of uniform quality throughout.

Breaking-down Point of Tool.—With the high-speed-steel tools it was not necessary to submit the cutting edges of the tools to microscopic examination, as it was found possible to obtain a definite point at which the tool failed to cut, or broke down. This is the point at which the working cutting-edge collapses, and, instead of continuing to cut, causes the surface of the bar to become highly polished. The exact instant at which each tool broke down, or began to produce this polished surface, was observed, and from this the exact duration of the test was determined.

Fig. 24.

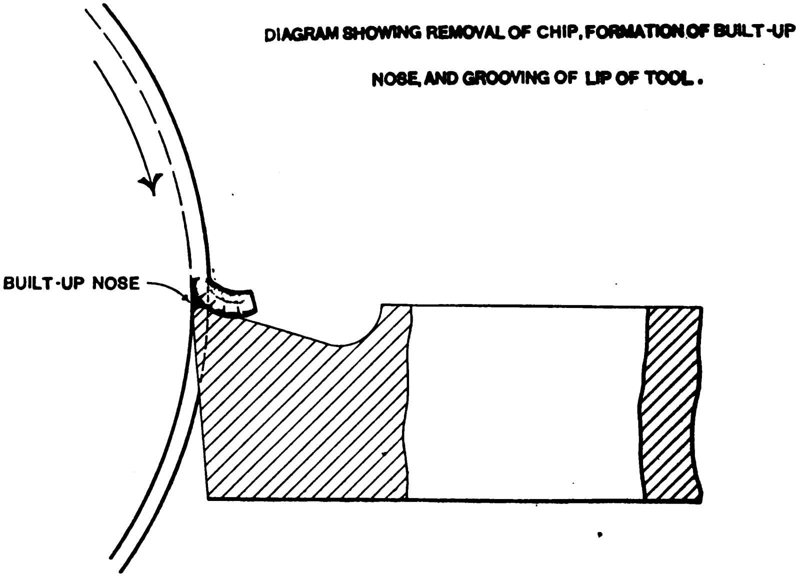


DIAGRAM SHOWING REMOVAL OF CHIP, FORMATION OF BUILT-UP NOSE, AND GROOVING OF LIP OF TOOL.
BUILT-UP NOSE

Standard Duration of Test.—In these tests a standard life of tool of 60 minutes was selected as being a convenient value. It is true that in machine-shops high-speed tools are usually allowed to run for a much longer period than this before resharpening, and the curves of performance seem to suggest that this practice has a reasonable basis, since the cutting speed which corresponds to a life of 60 minutes is in practically every case but about 5 or 10 per cent. greater than that which will allow a tool to last for, say, three or four hours.

The failure of a high-speed turning tool working under normal conditions is, in most cases, brought about by the fusing of the nose due to the heat generated as the result of friction. The friction is due: (1) to the rubbing of the chip on the upper lip of the tool as it passes off from the work (*see* Fig. 24). This rubbing action frequently causes a pit or hollow to be worn out of the upper face or lip of the tool just in front of the cutting edge as shown in Fig. 24; (2) to the friction due to the cutting action of the tool as it traverses the work in a line parallel to the axis. When the tool is worked under conditions which are not excessively severe, the heat generated at the nose of the tool is conducted away as fast as it is generated, and thus the nose is not subjected to over-heating; but if the conditions of speed of cutting and of area of cut are such as to generate heating of the nose faster than the tool can conduct it away, fusing and breakdown at the nose takes place. Also, as the work proceeds, the tool accumulates heat from the nose backwards, and the rate of flow or conduction of the heat away from the nose correspondingly decreases, with an increasing tendency to accumulation of heat at the nose. In the case of high-speed tools, as with carbon-steel tools, in many cases a false point is built up upon the nose of the tool composed of fine particles scraped from the surface of the work, which gives the appearance of having been fused on to the nose, and which no doubt is continually being ground away in the process of rubbing of the chip upon it, as well as replenished by the process of building up. There does not appear to be the same cumulative blunting of the high-speed tool as is the case with the carbon-steel tool, but when once the cutting edge of the tool is damaged, heating, fusing, and breakdown occur almost instantaneously.

The Tests.—A copy of the observation test-sheet is given in Appendix VI (page 1141), and the data taken include the circumferential or cutting speed, the depth of cut, the feed per revolution of the test-bar, the power-input to the motor on light load at the cutting speed selected, the time of starting the cut, the power-input to the motor during the actual cutting, and the time at which the tool failed.

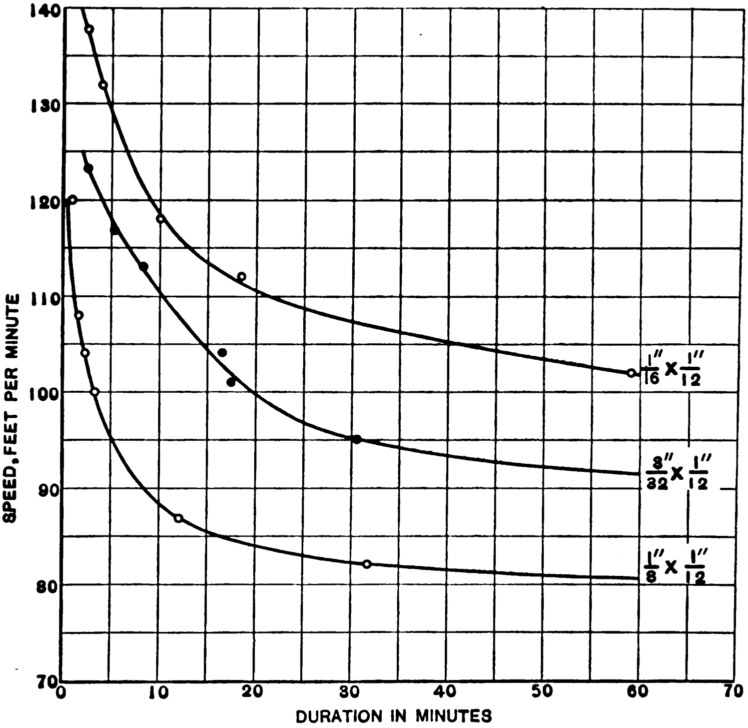
The tools were tested for the following areas of cut on each bar:—

Depth of cut. inch.		Feed per revolution. inch.
$\frac{1}{16}$	×	$\frac{1}{30}$, $\frac{1}{20}$, $\frac{1}{12}$, $\frac{1}{8}$
$\frac{3}{32}$	×	,, ,, ,, ,,
$\frac{1}{8}$	×	,, ,, ,, ,,

Fig. 25.

CUTTING SPEED AND DURATION TESTS FOR VARYING AREAS OF CUT.

HIGH-SPEED TOOLS ON MILD STEEL.



Relation between Cutting Speed and Durability of the Tool.—Altogether upwards of 200 tests were made, the duration of each test ranging from about 1 minute to 70 minutes. For each area of

Fig. 26.

CUTTING SPEED AND DURATION TESTS FOR VARYING AREAS OF CUT.

HIGH-SPEED TOOLS ON
MEDIUM STEEL.

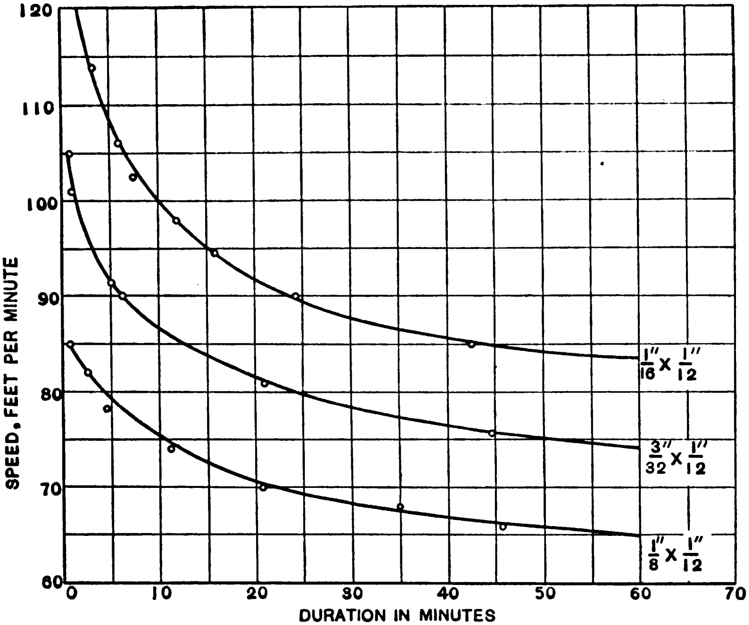
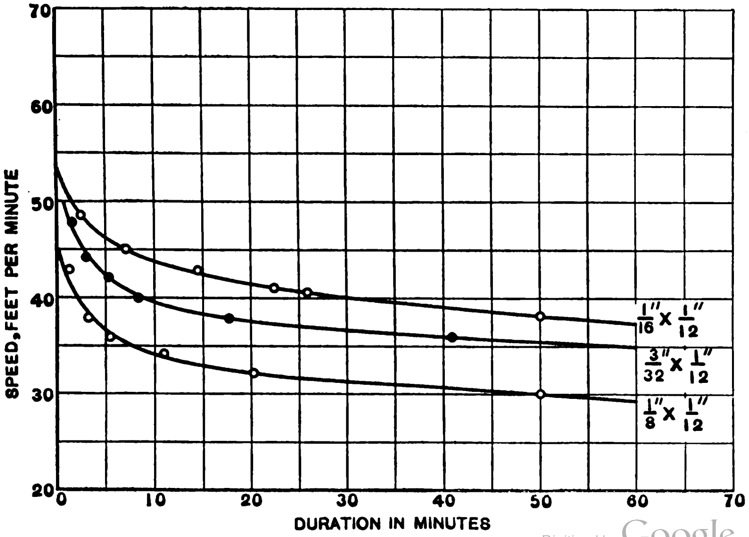


Fig. 27.

CUTTING SPEED AND DURATION TESTS FOR VARYING AREAS OF CUT.

HIGH-SPEED TOOLS ON
HARD STEEL.

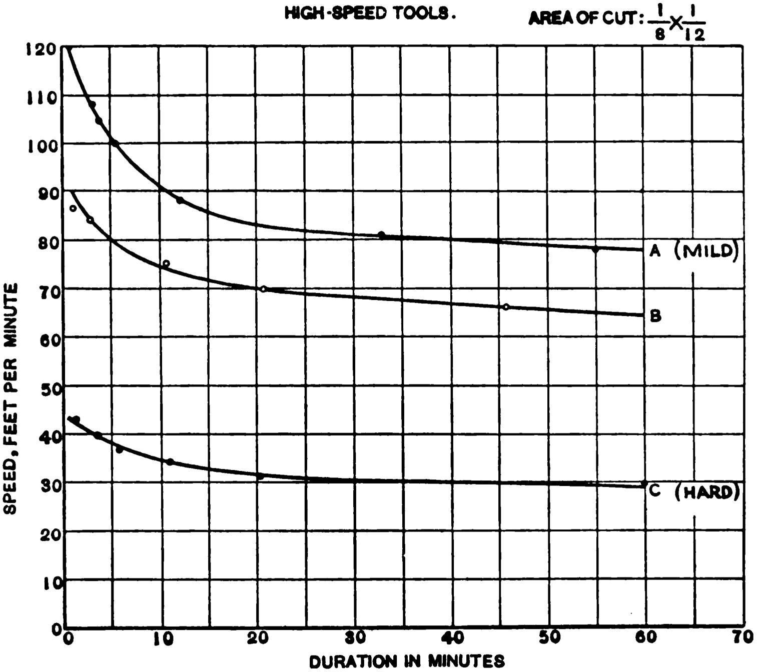


cut (or rather combination of depth of cut and feed per revolution) data for a cutting speed-duration curve were obtained, and curves Figs. 25, 26, and 27 (pages 1096–7) were plotted as shown. The curves in the figures are identified with the bars as follows:—

Fig. 25	Bar A (mild steel)
„ 26	„ B (medium steel)
„ 27	„ C (hard steel)

Fig. 28.

CURVES SHOWING EFFECT OF HARDNESS OF BAR ON DURABILITY OF TOOL.



The curves are for a feed of $\frac{1}{12}$-inch per revolution of the test-bar, the depth of cut in each case being stated on the curve.

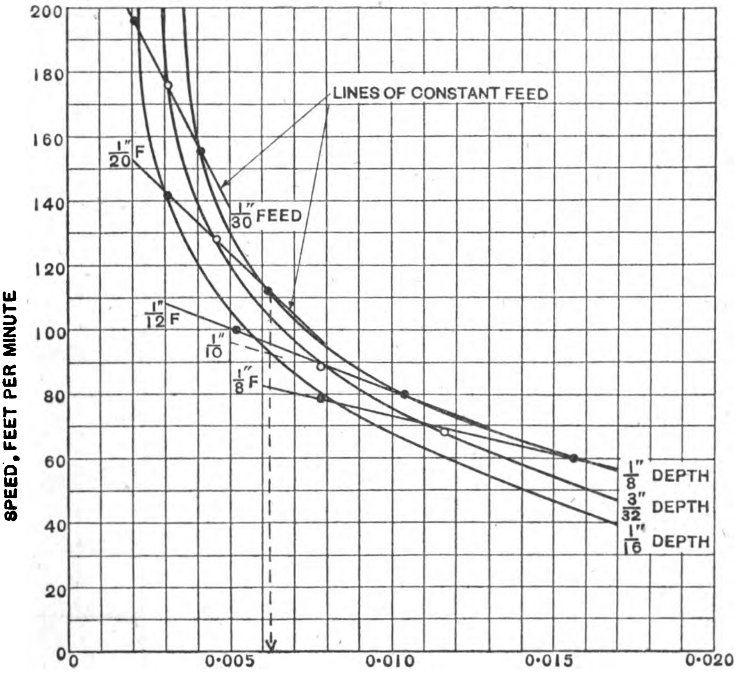
These curves, Figs. 25, 26, 27, 28, when compared with the corresponding curves for the carbon-steel tools, Figs. 12, 13, 14 (pages 1081–2), show clearly the extraordinary difference in cutting speed area of cut, and output which is possible with the use of high-speed tools of the same section as in the carbon-steel tool tests.

The curves also show the effects of hardness of the bar, and area of cut, on the cutting speed, and the relation between the cutting speed and the life of the tool up to the point of breakdown or failure. They further indicate (as do the corresponding curves for the carbon-tool tests) that at high cutting speeds the durability of the cutting edge is very short, but that as the rate of cutting is reduced to a speed which permits of a durability of 40 or 50 minutes the tool then continues to cut for a more or less indefinite period, as indicated by the approach of the curves to the horizontal. If this speed is, however, exceeded by from 10 to 15 per cent., the life of the tool is rapidly shortened.

Fig. 29.

RELATION BETWEEN CUTTING SPEED AND AREA OF CUT FOR VARYING CONDITIONS OF DEPTH AND FEED.

MILD-STEEL BAR. HIGH-SPEED TOOLS.



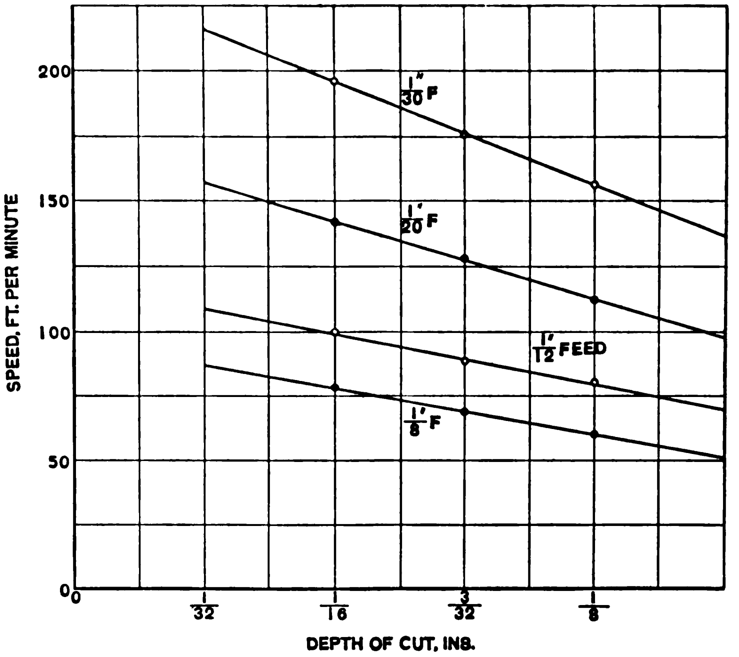
The average relation between the cutting speeds and the life of the tool M in minutes for any given area of cut between durations of 10 and 60 minutes is represented approximately by the formula

$$S \times M^{\frac{1}{8}} = \text{constant}, \quad . \quad . \quad . \quad . \quad (5)$$

Fig. 30.

RELATION BETWEEN CUTTING SPEED AND DEPTH OF CUT FOR VARYING FEEDS FOR A STANDARD LIFE OF 60 MINUTES.

MILD-STEEL BAR. HIGH-SPEED TOOLS.



The value of the constant depends, as before, upon the quality of the steel being turned and upon the area of cut. The relation between these two quantities, as determined by Mr. F. W. Taylor for high-speed turning tools, is

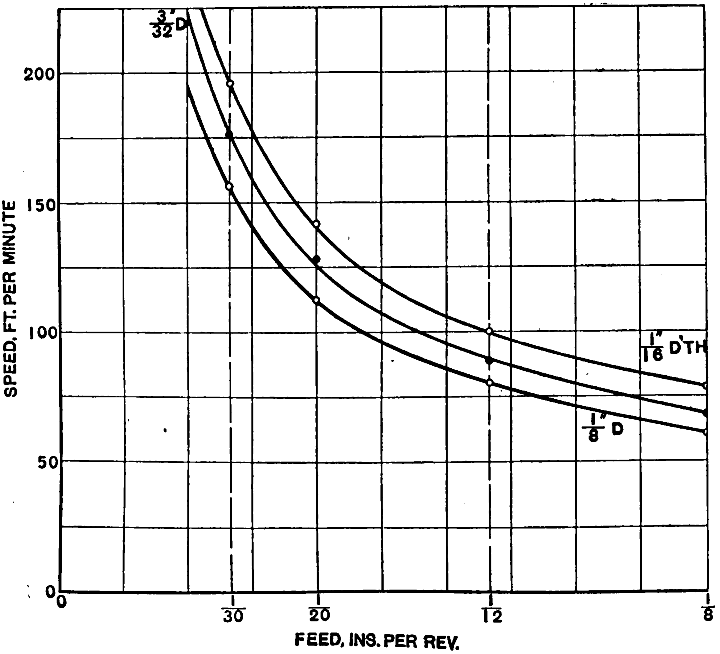
$$SM^{\frac{1}{8}} = \text{constant}.$$

Relation between Cutting Speed and Area of Cut.—For each test-bar the relation between the cutting speed and the associated area of cut for a standard life of 60 minutes was determined, the data in regard to the cutting speed being drawn from the curves of which Figs. 25, 26, and 27 are representative. Contrary to the experience and views of Dr. Nicolson,[*] and in agreement with those of Mr. F. W. Taylor,[†] it was found that the cutting speed did not depend only upon the area of cut as such, independently of its component factors, but that it depended upon these factors, namely, the depth of cut and the feed per revolution, in two different ways. Thus referring to the curves on Fig. 29 and taking a cut $\frac{1}{8}$-inch deep and

FIG. 31.

RELATION BETWEEN CUTTING SPEED AND FEED FOR VARYING DEPTHS OF CUT FOR A STANDARD LIFE OF 60 MINUTES.

MILD-STEEL BAR. HIGH-SPEED TOOLS.



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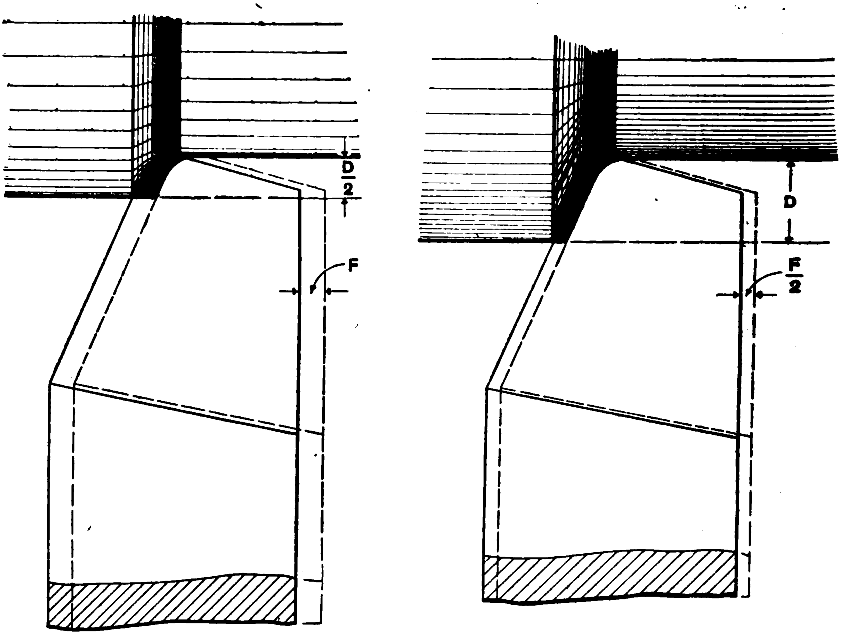
[*] Proceedings, Manchester Assoc. of Engineers, 1903, page 225.

[†] Proceedings, A.S.M.E., Vol. 28, No. 3.

$\frac{1}{20}$-inch feed, it is seen that the associated cutting speed belonging to these conditions is 112 as measured from the top curve, where it is intercepted by the $\frac{1}{20}$-inch constant feed line. Now taking the same area of cut, made up by a cut $\frac{1}{16}$-inch deep and $\frac{1}{10}$-inch feed, the associated cutting speed under these conditions as measured from the bottom curve for the same area of cut is 93. In other words, the output in the two cases would not be the same, but in the ratio of 112 to 93 in favour of the deep cut over the large feed. This is further explained in Figs. 30 and 31, in the former of which the relation between the cutting speed for standard tool life and the depth of cut is shown for the various feeds adopted, whilst in the latter the relation between the cutting speed and the feed per revolution is given for the various depths chosen, the curves referring to bar A in each case.

Figs. 32 and 33.

DIAGRAMS SHOWING EFFECT OF DEPTH AND FEED ON LENGTH OF CUTTING EDGE.



It is seen in Fig. 30 that a cut $\frac{1}{8}$-inch deep by $\frac{1}{20}$-inch feed is taken at a greater cutting speed than a cut $\frac{1}{16}$-inch deep by $\frac{1}{10}$-inch feed which is of equal area, but less efficient as a means of output, as already explained. A similar deduction can be made from Fig. 31 where it is seen that a cut, say, $\frac{1}{8}$-inch deep by $\frac{1}{24}$-inch feed is taken at a greater cutting speed, namely 125 feet per minute, while a $\frac{1}{16}$-inch deep by $\frac{1}{12}$-inch feed is taken at 100 feet per minute.

Some explanation of this is given in Figs. 32 and 33. In each of these figures a tool having the standard shape of nose is represented taking a cut of a definite area, this area being the same in the two cases. In the case of Fig. 32, the depth is one-half of that in the case of Fig. 33, while the feed per revolution is twice as great. It will be noticed that the length of the cutting edge which is in contact with the work in the first case is considerably less than the corresponding dimension in the second case; and there is, in the second case, therefore, a correspondingly larger cooling area behind the cutting edge to conduct the heat away as it is generated than there is in the first case. Under such circumstances, therefore, other things being equal, the rise in temperature of the cutting edge of the second case will not be so rapid as that occurring in the first case. In other words, a higher cutting speed can be employed with the tool having the longer cutting edge.

An examination of Figs. 30 and 31 (pages 1100–1) shows that the cutting speed is a linear function of the depth of cut, whilst it depends upon some power of the feed per revolution other than the first. The relation deduced from the above figures is:—

$$S = \frac{K_1}{(\text{feed})^{\frac{2}{3}}} - (K_2 - K_3 \text{ feed}) \text{ depth} \quad . \quad . \quad (6)$$

in which S = the cutting speed in feet per minute, and K_1, K_2, and K_3 are constants, the values of which depend upon the quality of the steel being machined. For the three bars A, B, and C, the constants are as follows:—

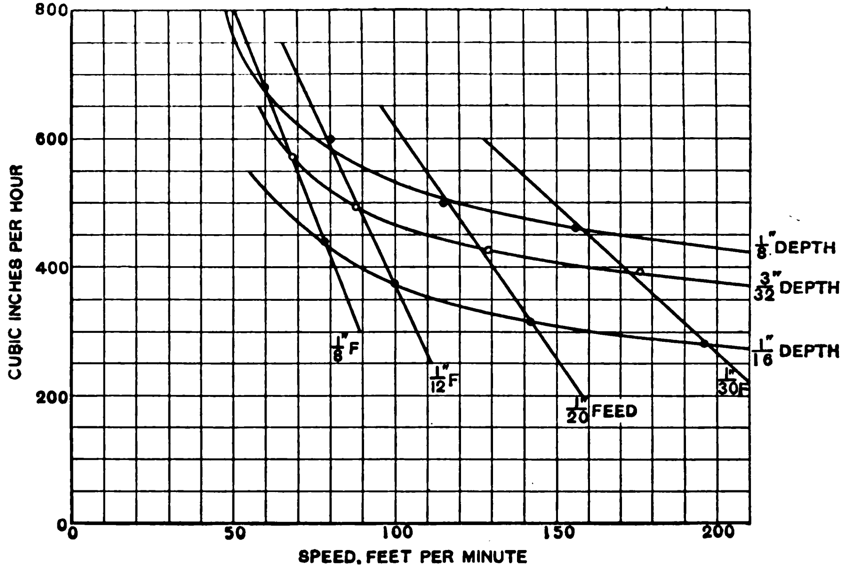
——	Bar A.	Bar B.	Bar C.
K_1 . . .	24	21	9
K_2 . . .	780	584	268
K_3 . . .	4,000	3,340	1,530

As will be shown later, however, the above formula may be reduced to a simpler though somewhat approximate form.

Fig. 34.

RELATION OF OUTPUT TO CUTTING SPEED, FEED, AND DEPTH OF CUT.

MILD-STEEL BAR. HIGH-SPEED TOOLS.



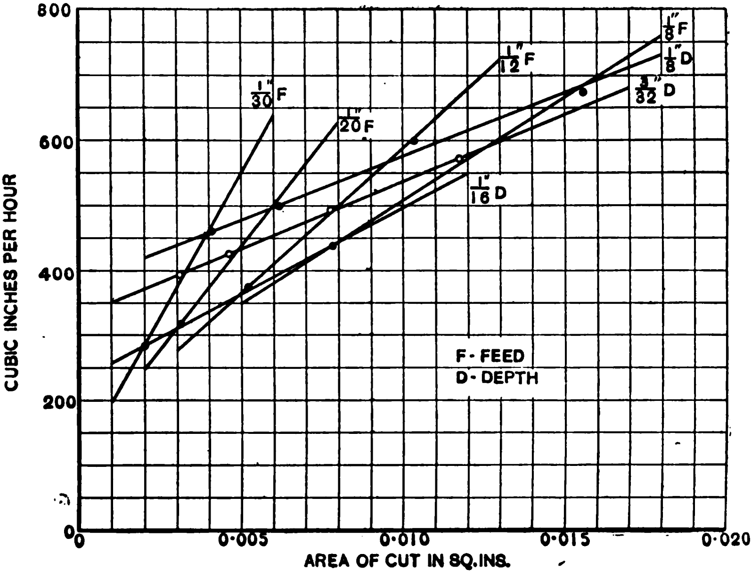
Output of High-Speed Tools.—The standard output of a high-speed turning tool is defined in these tests as the number of cubic inches which the tool will remove in the standard life of a tool, that is, in a run of 60 minutes and breakdown at that point. This volume of material for each cutting speed and associated depth-feed combination has been calculated from data obtained by measurement from the curves for the three bars, and the relation between this quantity and the cutting speed determined for each case. The curves for bar A are given in Fig. 34; the curves for the other bars are similar in form.

This figure shows that the maximum output, or removal of metal, is associated with the lowest cutting speed, with which, for a standard life of 60 minutes, the heaviest depth-feed combination is associated; the greater influence being, of course, on the side of the depth. Thus, with a depth of cut of $\frac{1}{8}$ inch and a feed of $\frac{1}{20}$ inch per revolution, the volume of metal removed in 60 minutes is 504 cubic inches; whilst, with a depth of cut of $\frac{1}{16}$ inch (or one-half of the above) and double the feed, namely $\frac{1}{10}$ inch, the output is 405 cubic inches per hour. This shows a gain of about 25 per

Fig. 35.

RELATION OF OUTPUT TO AREA OF CUT, FEED, AND DEPTH OF CUT.

MILD-STEEL BAR. HIGH-SPEED TOOLS.



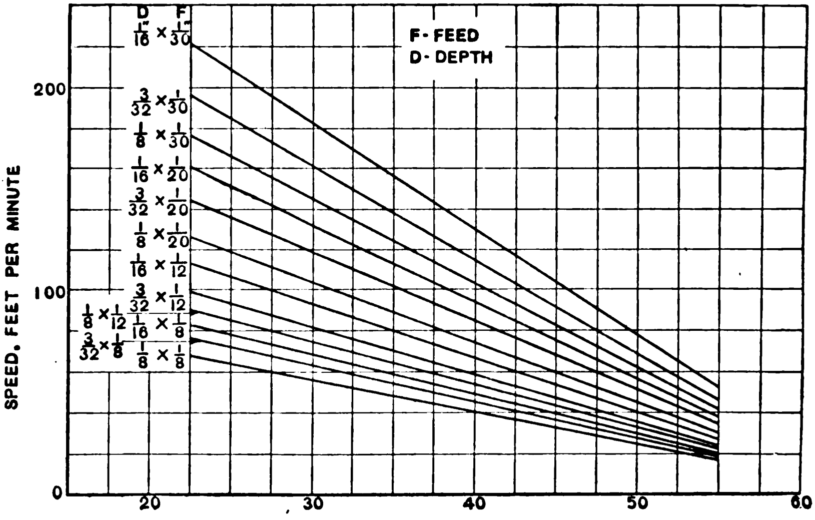
cent. of output in favour of the deeper cut with a reduced cutting speed. This law applies generally to all the bars and speed-depth-feed combinations. Hence, it may be stated that for the maximum tool output, the area of cut is a maximum which the tool will stand without fracture, with the depth of cut a large factor, and the associated speed correspondingly low.

This is also indicated in Fig. 35, which shows the relation

Fig. 36.

RELATION BETWEEN CUTTING SPEED AND HARDNESS OF BAR.

HIGH-SPEED TOOLS.



between the area of cut and the output of the tool. From an examination of this figure, it will be seen that for any given area of cut the tool output is reduced if the depth of cut is reduced and the feed is correspondingly increased, this being due to a consequent reduction in the associated cutting speed for a standard life of 60 minutes. On the other hand, if the depth is increased and the feed is reduced accordingly, then the tool output is increased. This is due, of course, to an increase in the associated cutting speed.

Relation between Cutting Speed and Hardness of Bar.—In Fig. 36 is shown the relation between the tensile strength of the metal being machined and the associated cutting speed for the different depth-feed combinations used in the tests. These lines show the general condition of a fall in working cutting speeds as the area of the cut is increased and as the hardness of the material to be cut is increased. The law is practically a straight-line law (as in the case of the carbon-steel tool tests), the equation to the law being—

$$S = \frac{(65 - T) \times 0{\cdot}207}{\sqrt[3]{\text{feed}^2 \times \text{depth}}} \quad . \quad . \quad . \quad (7)$$

in which S = the associated cutting speed in feet per minute, and T = the tensile strength of the metal being machined, in tons per square inch; or, for mild steel, this equation becomes—

$$S = \frac{8{\cdot}28}{\sqrt[3]{\text{feed}^2 \times \text{depth}}} \quad . \quad . \quad . \quad (8)$$

For Table of values of S for varying feed and depth of cut, *see* Appendix V (pages 1138–40), or the values of S for any quality of steel may be measured directly from Fig. 36.

This expression has been deduced in place of the more complicated expression (6) on page 1103, and though this is approximate it is only slightly so. In regard to expression (6), it should be pointed out that it could be arranged to include a function or functions of the tensile strength by determining the relation between the values of the constants, K_1, K_2, and K_3, and the tensile strength, since these—the constants—are the only quantities which depend upon the tensile strength, and they depend upon this only. Expression (7) is, however, a much simpler and more desirable form. It clearly shows that the influence of the depth of the cut is not the same as that of the feed upon the value of S, but that S is inversely proportional to the *cube root* of the *square* of the *feed* and to the *cube root* of the *depth.* This indicates, as do Figs. 29, 30, and 31 (pages 1099–1101) that for any given area of cut a higher "associated" cutting speed can be employed, with a corresponding increase in the output, when the cut is deep and the feed fine than when the cut is shallow and the feed coarse.

By the aid of this equation, it is easy to show the effect on the output of varying the ratio of these two factors with a constant area of cut; thus, for example, if the area of the cut is doubled by doubling the depth of the cut, the influence on the associated cutting speed is shown to be less than when this increase in area is effected by doubling the feed, as follows :—

By slightly modifying expression (7), we obtain—

$$S = \frac{K}{\text{Feed}^{\frac{2}{3}} \times \text{Depth}^{\frac{1}{3}}} \quad . \quad . \quad . \quad (9)$$

where $K = \{(65 - T) \times 0{\cdot}207\}$ and has the values given in Appendix IV (page 1137). Suppose, now, that the area of the cut is doubled by doubling the depth of the cut, the corresponding value of—

$$S_1 = \frac{K}{\text{Feed}^{\frac{2}{3}} \times (\text{Depth} \times 2)^{\frac{1}{3}}} = 0{\cdot}7938 \text{ S.}$$

If, however, the feed is doubled instead of the depth, we find that the corresponding value of—

$$S_2 = \frac{K}{(\text{Feed} \times 2)^{\frac{2}{3}} \times \text{Depth}^{\frac{1}{3}}} = 0{\cdot}6299 \text{ S.}$$

These figures demonstrate the point referred to above. Whilst there is only a 21 per cent. reduction in the cutting speed in the double-depth case, there is a 37 per cent. reduction in the double-feed case. Or, the double-depth cutting speed is 26 per cent. higher than that associated with the double-feed case; and since the two areas of cut are the same, the method which is associated with the higher cutting speed will, of course, produce the greater output.

The question of the influence, on the output, of the depth of cut and the feed per revolution, can also be considered directly by regarding the cutting speed as a function of the depth and feed. Thus, let V = the volume of metal, in cubic inches, removed per hour, then—

$$\begin{aligned} V &= 12\,S \times A \times 60 \\ &= 720\,S\,A \\ &= 720\,S\,F\,D \quad . \quad . \quad . \quad (10) \end{aligned}$$

where S, F, and D represent the cutting speed, the feed, and the depth respectively. Now, from expression (9), we have that—

$$S = \frac{K}{F^{\frac{2}{3}}\,D^{\frac{1}{3}}}$$

Therefore

$$V = \frac{720\text{ K FD}}{F^{\frac{2}{3}}\,D^{\frac{1}{3}}}$$

$$= 720\text{ K }F^{\frac{1}{3}}\,D^{\frac{2}{3}}$$

$$= CF^{\frac{1}{3}}\,D^{\frac{2}{3}} \quad . \quad . \quad . \quad . \quad (11)$$

C being a constant depending upon the tensile strength of the metal being turned, and being equal to {149 (65 – T)}, T being the tensile strength, in tons per square inch, of this metal.

The influence on the speed, and therefore on the output of a change of feed for any given area of cut is also shown from the following: as before—

$$S = \frac{K}{F^{\frac{2}{3}}\,D^{\frac{1}{3}}}$$

$$= \frac{K}{\sqrt[3]{F^2 \times D}}$$

But FD = A (area of cut); therefore—

$$S = \frac{K}{\sqrt[3]{A \times F}} \quad . \quad . \quad . \quad . \quad (12)$$

This shows that if A is maintained constant,

$$S = \frac{\text{constant}}{F^{\frac{1}{3}}} \quad . \quad . \quad . \quad . \quad (13)$$

Shape of Cutting Edge.—As in the case of the carbon-steel tool tests, the effect of a change in the shape of the nose of the tool and in the disposition of the cutting edge of the nose with respect to the axis of the test-bar was considered. The change of the shape was made from the standard, Fig. 1 (page 1071), to the shape illustrated in Fig. 21 (page 1088). The test conditions were exactly the same as in those of the previous tests. Sample comparative curves are shown in Fig. 37 (page 1110). Curves E and E_1 are for the same area of cut ($\frac{1}{16}$-inch by $\frac{1}{12}$-inch) for the two different shapes of nose on the same bar, E representing the standard, Fig. 1, and E_1 the second shape.

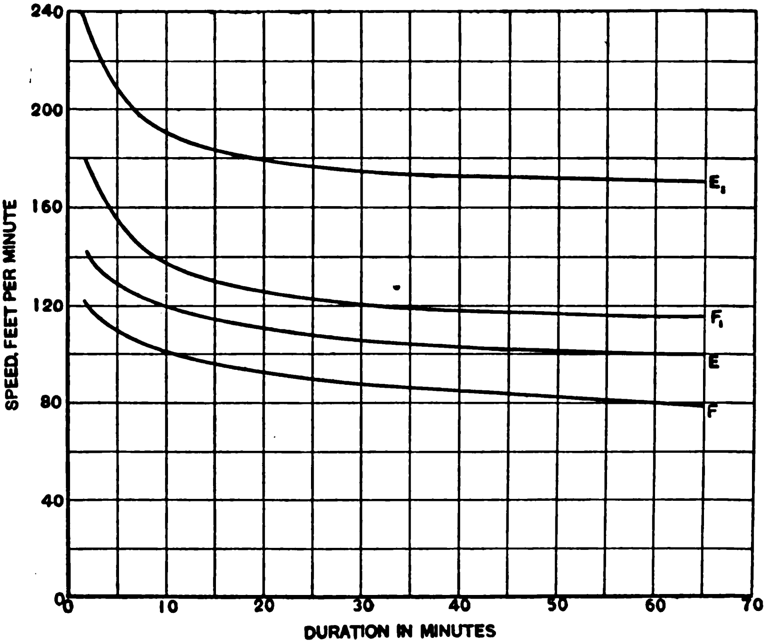
Curves F and F_1 are corresponding curves for another area of cut ($\frac{1}{16}$-inch by $\frac{1}{8}$-inch).

An examination of these curves will show that, for a life of 60 minutes, the second shape of nose will, other things being equal, admit of a higher cutting speed being employed, and will therefore be capable of greater output.

Fig. 87.

EFFECT OF SHAPE OF NOSE ON CUTTING SPEED FOR STANDARD LIFE OF TOOL.

HIGH-SPEED TOOLS.



Comparison between High-Speed and Ordinary Carbon-Steels.

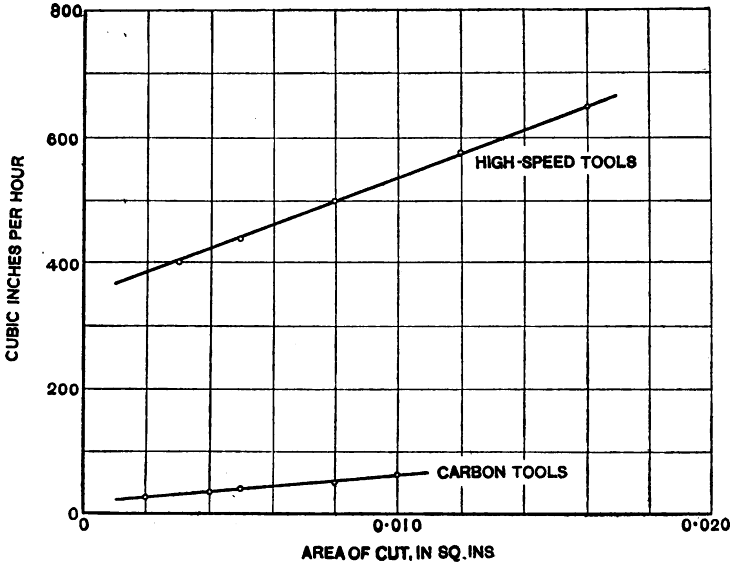
Tools of Small Section. (*$\frac{3}{4}$-inch by $\frac{1}{2}$-inch.*)

For an area of cut, $\frac{1}{8}$-inch by $\frac{1}{12}$-inch, the cutting speed which will allow the tool to last one hour under the above conditions is 78 feet per minute for the high-speed tool, and 8 feet per minute for the plain carbon-steel tool on a bar having a tensile strength of about 25 tons per square inch. This ratio is about 10 : 1. That is, for a cut as above, the high-speed tool will remove ten times as much metal from stock as will the plain carbon-steel tool in a given time; or it will remove any given amount in one-tenth of the time.

A graphical comparison of the performances of high-speed and plain carbon turning tools is shown in Fig. 38.

Fig. 38.

RELATIVE OUTPUT OF HIGH-SPEED AND CARBON STEEL TOOLS.



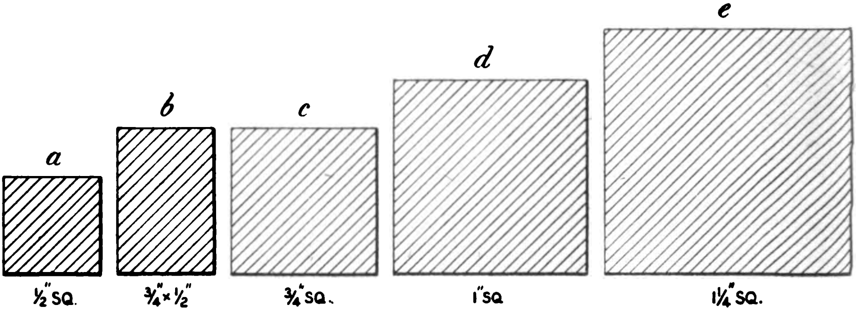
Relation between Output and Cross-Sectional Area of Tool-Steel.

To find the effect on the output of the use of high-speed tool-steels of various cross-sectional areas, a number of experiments were made with tool-steels of sections shown in Fig. 39, commencing with ½-inch square section, and proceeding to ¾-inch by ½-inch; ¾-inch square; 1 inch square; and 1¼ inch square. All these tools were prepared with a cutting edge of exactly similar geometrical form at the cutting nose, the form being the same as already illustrated in Fig. 1 (page 1071). The tools were all tested on one common mild-steel test-bar A about 20 inches diameter and 10 feet long, with a composition given in Appendix III (page 1136).

The object of the tests was to determine the maximum output with tools of each of the above sections, and then to compare the relations of these outputs with one another. The method adopted for determining the maximum output was to employ the "speed-increment" test described later (page 1119). An experiment was first made upon sample tools of each section to find what depth of cut the tool would take, with a given feed, to break it down in exactly 20 minutes. It was found possible to adjust the depth of cut in such a way that the tool would break down within a few seconds above or below the 20 minutes period. The feed was kept constant at $\frac{1}{12}$-inch per revolution throughout all the tests. The commencing cutting speed chosen was 75 feet per minute, and the cutting speed was increased by 1 foot per minute speed increments, every minute, until the breaking-down point was reached. The breaking-down cutting speed in each case was therefore 95 feet per minute. The total material turned off during the test for each particular tool section is proportional to the respective depths of cut employed. The results of the tests are plotted on Fig. 40, and a curve drawn through the points *a*, *b*, *c*, *d* and *e* representing the results obtained respectively with the tools of the above sections.

FIG. 39.

SECTIONS OF TOOL STEEL TESTED.

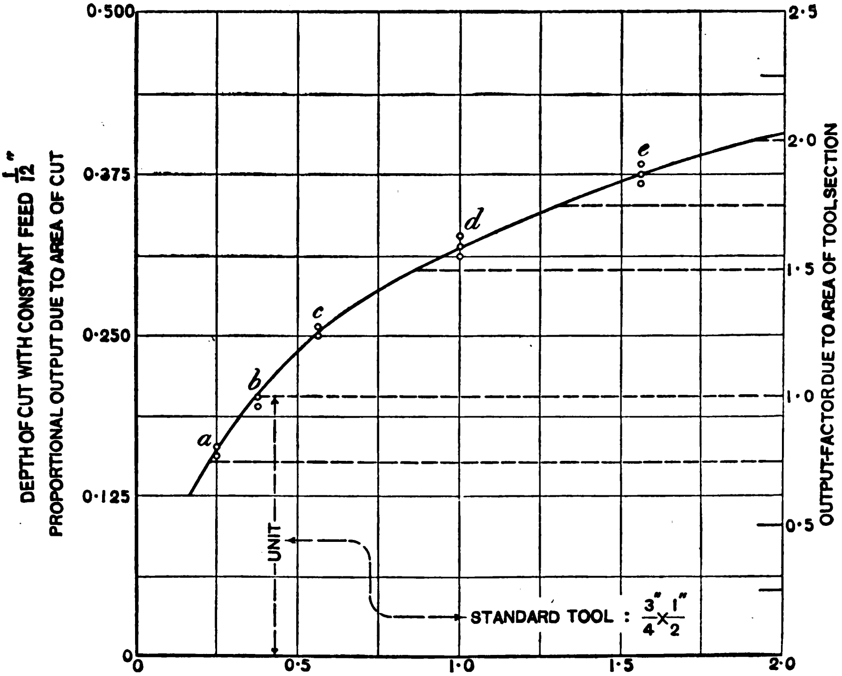


The tool taken as the standard or unit section was the ¾-inch by ½-inch, this being the size of tool employed throughout all the tests mentioned in the previous parts of the Paper (*see b*, Fig. 40).

From this curve it is now possible to convert the output obtained with a cutting tool of any given section into its equivalent output for any other given section, each working respectively with its appropriate or associated area of cut. Since the speeds in these tests were similar for each size of tool, the respective output factors represent actually the proportional areas of cut taken by the standard tool. Thus, taking the ¾-inch × ½-inch as the unit, the following Table

Fig. 40.

EFFECT ON OUTPUT OF CROSS-SECTIONAL AREA OF TOOL STEEL.



AREA OF TOOL SECTION, IN SQ. INS.

of factors is prepared so that when the output given by the $\frac{3}{4}$-inch × $\frac{1}{2}$-inch tool is known, this output multiplied by the factor opposite the required section of tool-steel gives the equivalent output for that section. The factor is also shown on a scale on the right-hand side of Fig. 40.

The relation between the cross-sectional areas of the tool-steels and the associated depth of cut with constant feed and constant average cutting speed is found to be given approximately as follows:—

$$D = \sqrt{a} \times \text{constant}, \qquad . \quad . \quad . \quad . \quad (14)$$

in which D = the depth of cut (with a constant feed and constant average cutting speed) and a = the cross-sectional area of the tool-steel; also

$$\text{Output} = \sqrt{a} \times \text{constant}. \qquad . \quad . \quad . \quad (15)$$

Equivalent Output for Tool-Steels of various sections.

Section of Tool-Steel.	Output Factor.
Inches. Inches.	
$\frac{1}{2}$ × $\frac{1}{2}$	0·80
$\frac{3}{4}$ × $\frac{1}{2}$	1·00
$\frac{5}{8}$ × $\frac{5}{8}$	1·17
$\frac{3}{4}$ × $\frac{3}{4}$	1·27
$\frac{7}{8}$ × $\frac{7}{8}$	1·43
1 × 1	1·60
$1\frac{1}{8}$ × $1\frac{1}{8}$	1·73
$1\frac{1}{4}$ × $1\frac{1}{4}$	1·87
$1\frac{3}{8}$ × $1\frac{3}{8}$	2·00

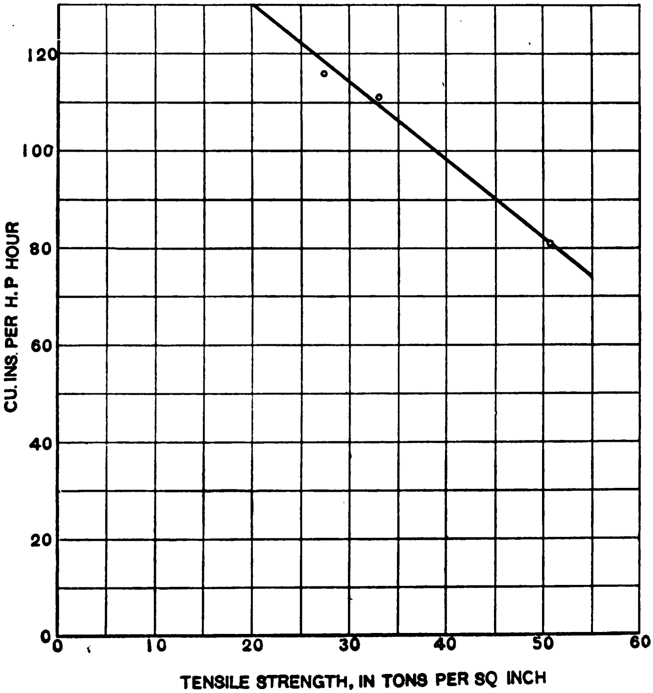
RELATION OF MOTOR POWER TO OUTPUT.

To determine the relations existing between the area of cut, the associated speed, and the actual horse-power requirements, tests were made on the different bars with the various adopted depths of cut and feeds and their associated cutting speeds, the power consumption in each case being obtained by taking voltmeter and ammeter readings. These readings were taken when the cut was in, and again when it was not in (the speed being the same in each case), the net horse-power (that is, the horse-power required to accomplish the actual cutting) being calculated from the difference between the two readings.

Fig. 41.

RELATION OF OUTPUT PER NET H. P. HOUR TO TENSILE STRENGTH OF BAR TURNED.

HIGH-SPEED TOOLS.



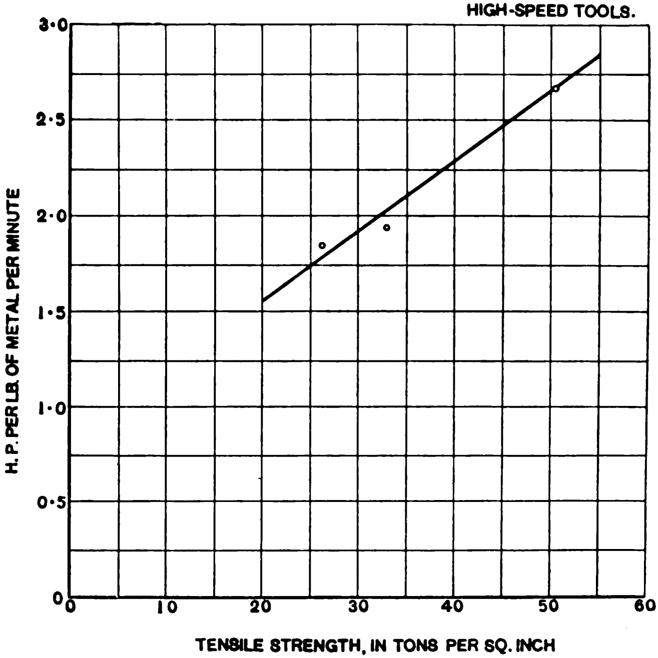
The results are given in the accompanying Tables, Appendix V (pages 1138–40), in which also the number of cubic inches removed per horse-power hour is given for each case.

It will be seen that the actual net horse-power required to remove a given number of cubic inches per hour is a constant for each quality of steel machined. In other words, the output per horse-power hour is practically a constant quantity. That is, for a given output per hour there is nothing to gain from the point of view of economy in net power consumption by altering the ratio of area of cut to speed of cutting, the net horse-power required being approximately directly proportional to output only.

Fig. 42.

RELATION OF NET H. P. PER LB. OF OUTPUT PER MINUTE TO TENSILE STRENGTH OF BAR TURNED.

HIGH-SPEED TOOLS.



Another point to observe is that the number of cubic inches removed per horse-power hour depends upon the hardness of the bar being machined; the harder the bar the less the number of cubic inches removed per horse-power hour.

If the results of the experiments shown in the Tables are plotted, and an average line be drawn through the points, an approximate law can be determined showing the relation of output in cubic inches per horse-power hour to hardness of bar. This line is drawn in Fig. 41, and the law determined from it is found to be given by the formula

$$\text{Cubic inches per h.p. hour} = \{167 - 1{\cdot}7\ \text{T}\}, \quad . \quad (16)$$

where T = tensile strength in tons per square inch; or, expressed as weight W in lb. per h.p. per hour,

$$\text{W} = \{47 - 0{\cdot}48\ \text{T}\}. \quad . \quad . \quad (17)$$

Again, if the tensile strength of the material being turned is plotted against the net horse-power required per lb. of material turned off per minute, it will be found that the power required for any given quality of bar (*see* Fig. 42) is expressed by the formula

$$\text{Net h.p. per lb. per minute} = \{0{\cdot}8 + 0{\cdot}037\ \text{T}\} \quad (18)$$

Thus, taking T = 25 tons per square inch, we have

$$\begin{aligned}\text{Net h.p. per lb. per minute} &= 0{\cdot}8 + 0{\cdot}037 \times 25 \\ &= 1{\cdot}725.\end{aligned}$$

It should be noted that the power given above does not include the power required to drive the lathe itself when running with the cut withdrawn. The additional power required to drive the lathe, when the cut is in, includes: (i) the power required to perform the operation of cutting, together with (ii) the additional friction of the lathe-saddle on its bed due to the pressures on the tool. The latter item (ii) is small, and the whole additional power is therefore debited to the process of cutting.

Conclusions from High-Speed Tool Tests.

1. The breaking-down point of a high-speed tool is usually well defined, it being indicated by a more or less sudden refusal on the part of the tool to cut, accompanied by a polishing of the surface of the work due to collapse by fusion at the cutting edge.

2. Within the limits of the authors' experiments, the durability

of high-speed steel tools is in all cases some function of the reciprocal of the cutting speed, in other words, the higher the cutting speed the shorter the durability, and vice versa.

3. For a reasonable working duration or life of a tool (say, 60 minutes as a standard) high-cutting speeds are invariably associated with light cuts, and low-cutting speeds with heavy cuts; that is, high-cutting speeds and heavy cuts do not co-exist.

4. The cutting speed, which is associated with a given area of cut to permit of a given or standard life of tool, depends upon the relation between the depth of the cut and the feed per revolution, so that there is a definite "associated" cutting speed for any area of cut for each of the ways in which the depth and feed are combined to form the area.

5. If the area of the cut is kept constant, a higher associated cutting speed is obtainable when the cut is deep and the feed fine, than when the cut is shallow and the feed coarse.

6. A tool working at a low-cutting speed with its associated depth-feed combination will accomplish a greater output in the standard life of the tool than will a tool which is working at a high cutting speed with its associated depth-feed combination.

7. For maximum tool output the area of the cut employed is the maximum which the tool will stand without fracture, with the depth of cut a large factor and the associated cutting speed correspondingly low.

8. The associated cutting speed for any depth-feed combination depends upon the quality of the material which is being operated upon, a high-cutting speed being associated with a low degree of hardness, and vice versa.

9. A tool with a long cutting edge has a longer life (under similar conditions of depth of cut, feed per revolution, cutting speed, and tensile strength of the metal being machined) than one which has a short cutting edge.

10. The number of cubic inches removed per net horse-power hour is practically a constant quantity for each quality of material turned when the tools work under the standard conditions, whatever the area of cut or depth-feed combination.

There is, therefore, no economy in energy-consumption to be gained by using high- or low-cutting speeds, or light or heavy cuts, provided that the tools work under standard associated conditions of speed and cut.

There is, however, an economy in time-consumption to be gained by using low-cutting speeds and the heavy cuts associated with them.

THE SPEED-INCREMENT TEST FOR TURNING TOOLS.*

Since the introduction of high-speed steel for turning and other tools, the question of the comparative testing of steels of this kind has become a very important one, both to the manufacturer and to the user of such steel. Comparative tests are necessary to the manufacturer in his efforts to improve the qualities and capabilities of his products (from the standpoint of chemical composition as well as of heat treatment); and to the user in his efforts to compare the various makes of steel of this kind, with a view to obtaining the best tool for any particular class of work.

The ordinary comparative test consists of running the test-bar at a constant circumferential speed (such as 60 feet per minute) and causing the tool to take a cut of standard dimensions until it breaks down or loses its cutting edge, the duration of the test, or the life of the tool under such circumstances, being taken as the criterion value by which to estimate the quality of the tool.

The method introduced and adopted by Mr. F. W. Taylor involves the selection of a fixed duration of test, namely 20 minutes the object of the test being the determination of the speed (under given and constant conditions of area of cut, etc.) at which the cut may be made to break down the tool in 20 minutes. To carry out this test satisfactorily, a fairly large number of tools must be made from the same bar of steel, the required number varying from four to eight.

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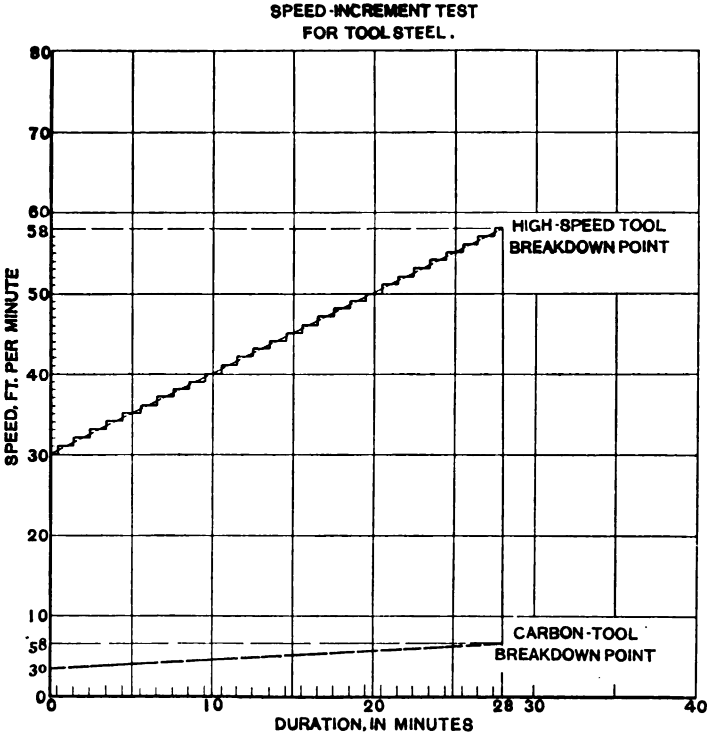
* A Paper describing an earlier form of this method of testing lathe tools was submitted by Dr. Ripper to the Engineering Section of the British Association in September 1910.

The method adopted in the machine-tool laboratory of the Sheffield University is one in which a uniformly accelerated cutting speed is the essential part. The form of the test is comparable with the method of applying the load in a tensile test. It has been designated the "Speed-increment Test," because starting at a definitely fixed cutting speed a constant increment of 1 foot per minute is added to this cutting speed every minute. The number of cubic inches which the tool removes up to the point of break-down is taken as the numerical value by which its quality is judged.

Fig. 43.

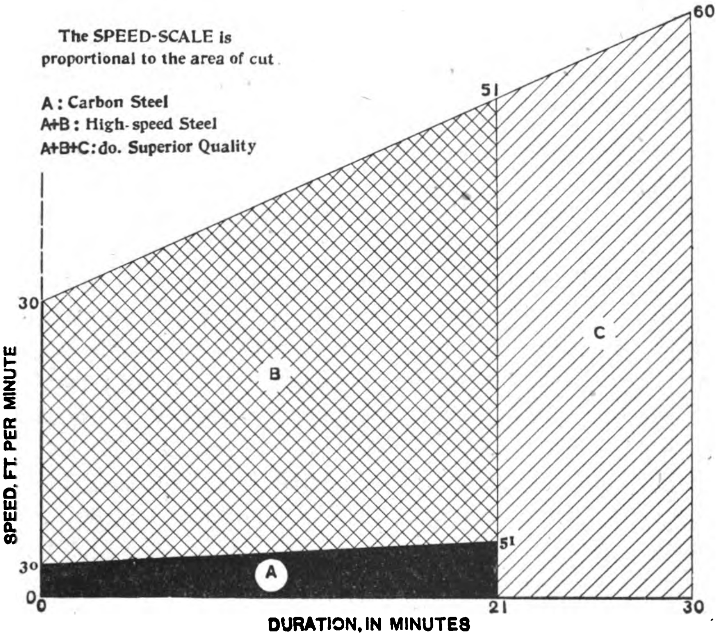


The principle of this test is as follows:—The tool is started to cut at a starting speed of 30 feet per minute with a standard area of cut on the test bar. By "standard area of cut" is meant the area of cut which will secure a test of about 20 minutes' duration for one tool of the set, its magnitude varying according to the hardness of the test-bar and the sectional area of the tool-steel. This area of cut, once decided, is used for each tool of the series.

This cutting speed is accelerated at the end of each minute at the rate of 1 foot per minute, to the end of the test, that is, until

Fig. 44.

AREAS REPRESENTING RELATIVE OUTPUT OF TOOL STEELS OF VARIOUS QUALITIES.



the break-down point of the tool is reached. At the beginning of the test the first speed of 30 feet per minute is run for ½ minute only, for the purpose of getting a straight average line on the output diagram, Fig. 43. In all other cases the time of running is a one-minute period for each newly accelerated speed.

From the data obtained during the test, the number of cubic inches of metal removed by the tool during the test can be calculated, this number being taken as the criterion value by which the quality of the tool is judged. This number equals the average cutting speed during the test in feet per minute × 12 × area of cut in square inches × duration of the test in minutes.

The speed-time curve for this test is indicated in Fig. 43. The stepped line indicates the progressive nature of the test for high-speed steel to the breaking-down point. Towards the bottom of the diagram the same method of test is shown for the carbon-steel tool. The vertical scale in the two cases is made proportional to the respective areas of cut. The vertical steps in the case of the carbon-steel tool are too small to be shown. The areas enclosed between the respective speed-increment lines and the base represent the amounts of material removed.

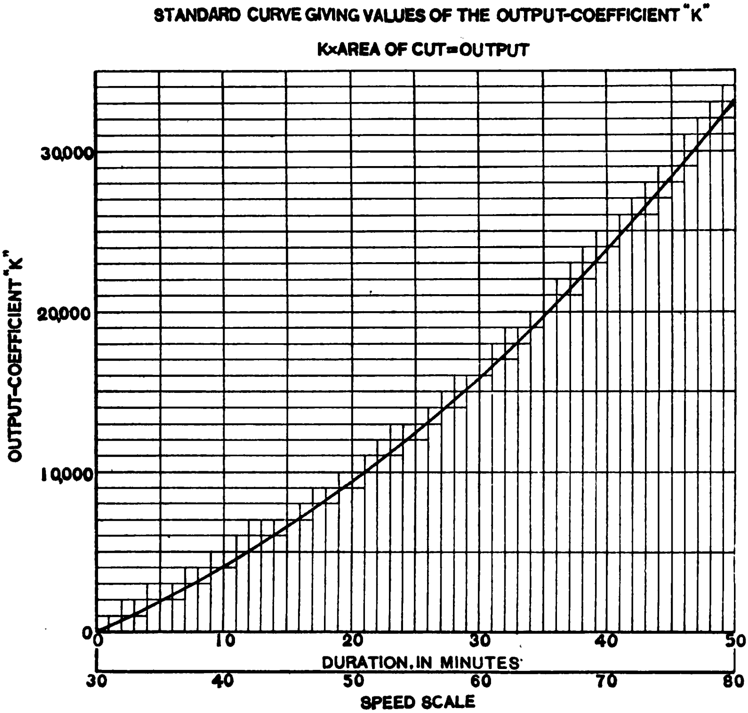
In Fig. 44 are represented the cases of three tools: (1) a plain carbon-steel tool; (2) an ordinary high-speed tool; and (3) a superior high-speed tool. In the case of (2) and (3) the same area of cut was used, but in the case of the first a much smaller area of cut had to be used, the ratio of the two areas being equal to the ratio of the speed scales of the figure. Tools Nos. (1) and (2) lasted for 21 minutes, whilst tool No. (3) lasted for 30 minutes. The output of the plain carbon-steel tool is represented by the area A; that of the ordinary high-speed tool by the sum of areas A and B; and that of the superior high-speed tool by the sum of areas (A + B) + C.

The final speed of cutting of the first high-speed tool was 51 feet per minute, and of the second high-speed tool 60 feet per minute, so that the mean cutting speeds were 40·5 and 45 feet per minute respectively. Therefore, the criterion values of these two tools were respectively $(40{\cdot}5 \times 21) = 850{\cdot}5$; and $45 \times 30 = 1{,}350$. The ratio of these two values, namely, $\frac{1{,}350}{850{\cdot}5} = 1{\cdot}5$, is the ratio between the two areas (A + B + C) and (A + B) represented in Fig. 44, the larger area representing the case of the better tool.

This test can only be made on lathes which are provided with means whereby the speed can be changed instantaneously (or nearly so) and in regular and definite amounts. For an explanation of the method employed, *see* Appendix I (page 1128).

To render elaborate calculations unnecessary in connection with this test, a curve, Fig. 45, which gives the relation between what has been designated the "output coefficient" and the duration, has been worked out. This coefficient is actually the length of the turning removed under the above conditions by the tool in inches in any given time, so that the number of cubic inches removed in that time is found by multiplying the constant for the time by the area of the cut. This renders the determination of the average speed during the test unnecessary.

Fig. 45.



The diagram, Fig. 45, is used as follows:—

The zero of the diagram represents the starting point of the test at the cutting speed of 30 feet per minute; at the end of

10 minutes the speed has obviously increased to $(30 + 10) = 40$ feet per minute; at the end of 20 minutes the cutting speed is $(30 + 20) = 50$ feet per minute, and so on.

To find the material turned off in the case of a tool which has broken down after a speed increment test of, say, 33 minutes, we take the value K from the diagram, which is 18,000. Multiplying this by the area of cut equals the output in cubic inches, which is the number representing the criterion value of the tool; thus for a cut $\frac{3}{8}$-inch by $\frac{1}{12}$-inch, we have 18,000 by $\frac{3}{8}$ by $\frac{1}{12} = 562{\cdot}5$ criterion number. A special feature of this method of testing tool-steels is the exceedingly regular results obtained when repetition tests are made.

The Paper is illustrated by 45 Figs. in the letterpress, and is accompanied by 6 Appendixes with Plate 36 and 4 Figs.

APPENDIX I.

(*See Plate* 36.)

DESCRIPTION OF THE TOOL-STEEL TESTING LATHE IN THE ENGINEERING DEPARTMENT OF THE UNIVERSITY OF SHEFFIELD.

This lathe was built by Messrs. Joshua Buckton and Co., of Leeds, and is of such a design that it can be employed for testing either high-speed lathe-tools or large twist-drills, the latter being made possible by a special arrangement provided in the loose headstock. It is an 18-inch centre lathe, the bed, however, being of the size usually provided on 20-inch lathes, thus giving extra stiffness to the lathe.

The overall length of the lathe, including the bed-plate of the main driving motor, is about 25 feet. The dimensions of the largest test-bar which can be carried between the centres are: length, 10 feet; and diameter, 25 inches. The test-bar is held by four independent dogs or jaws mounted on a large driving plate, which is carried by the main driving spindle. At the loose headstock end the bar is supported by an ordinary centre of ample proportions.

The lathe is driven by a 40-b.h.p. direct-current motor. This motor can actuate the driving plate on the main spindle in the headstock in two different ways: (1) directly, by coupling the armature of the motor to the main spindle; (2) indirectly, through gearing. The direct connection is obtained by means of a tongue on the headstock end of the motor armature shaft, and a corresponding slot in the motor end of the main spindle of the headstock. This mode of driving is only used when very high rotary speeds are required, as in the case of drill tests. The indirect connection is obtained by means of a pinion on the headstock end of the motor armature shaft, which engages with another pinion mounted on a gear shaft passing through the headstock.

In the headstock any one of three sets of gears can be used for transmitting the power and motion to the driving plate. This plate is driven by a toothed pinion, which works in gear with the teeth on the back portion of the rim of the driving plate, and which is an integral part of the plate. The power is thus transmitted directly to the rim of the driving plate and not through the main spindle. The gears are so arranged that only one set can be in action at the same time, and they are controlled by means of levers on the front of the headstock. The gears are: (1) single gear, giving driving-plate or spindle speeds from 50·5 to 202 revolutions per minute, according to the speed of the motor; (2) double gear quick, giving driving-plate speeds from 16 to 64 revolutions per minute; and (3) double gear slow, giving driving-plate speeds from 5 to 20 revolutions per minute. The gear ratios, including ratio between the driving pinion and driving-plate gear in each case, are as follows:—

Single gear	1 : 3·96
Double gear quick	1 : 12·50
Double gear slow	1 : 40·00

The slide-rest is of the ordinary compound type, having a top swivelling slide, with tool clamps, and a cross or surfacing slide. A large feed apron is provided on the slide-rest for carrying gears for power sliding and surfacing. The slide-rest is rack driven, the power being supplied to it by a feed shaft on the front of the lathe bed. This feed shaft can be actuated either directly from the main driving spindle in the headstock or by a separate feed motor.

Altogether eight different feeds (travel of the slide-rest per revolution of the test-bar) can be obtained for sliding, surfacing and drilling with the direct drive as follows :—

Clutch Lever.	Coarse.				Fine.			
Sliding-key Lever.	1	2	3	4	1	2	3	4
	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
Sliding . . .	$\frac{1}{4}$	$\frac{1}{6}$	$\frac{1}{8}$	$\frac{1}{12}$	$\frac{1}{20}$	$\frac{1}{30}$	$\frac{1}{40}$	$\frac{1}{60}$
Surfacing . .	$\frac{1}{8}$	$\frac{1}{12}$	$\frac{1}{16}$	$\frac{1}{24}$	$\frac{1}{40}$	$\frac{1}{60}$	$\frac{1}{80}$	$\frac{1}{120}$
Drilling . .	$\frac{1}{20}$	$\frac{1}{30}$	$\frac{1}{40}$	$\frac{1}{60}$	$\frac{1}{100}$	$\frac{1}{150}$	$\frac{1}{200}$	$\frac{1}{300}$

The feed-shaft drive from the independent feed motor is through a motor feed-gear box containing spur gear and clutches, so that fast and slow feeds are provided for. Feeds varying from 0·090 inch per minute to 200 inches per minute can be obtained when using the motor drive for the feed.

A graduated dial is mounted on the cross-slide screw, the divisions on the dial being $\frac{1}{64}$ of an inch, so that depths of cut varying by $\frac{1}{64}$ of an inch can be attained with great accuracy. The zero of the dial is adjustable.

The loose headstock is of massive proportions, the mandrel or spindle of this being so arranged that it can be fed along either by hand (when making slight adjustments) or by power for drill testing). On the tail end of the screw of the headstock is mounted a worm wheel, with which a worm can be put into mesh. This worm receives its motion from the feed shaft through spur and bevel gearing, and transmits to the screw through the worm wheel.

An auxiliary rack is provided on the bed for the special purpose of moving the headstock along the bed whenever required. This is done by means of a handle on the front of the headstock, which is connected to the rack through spur and bevel gears and rack pinion.

The lathe-bed is graduated in inches so that the travel of the slide-rest in any given time or for any given number of revolutions of the test-bar can be determined. A revolution counter is connected to the main spindle of the driving headstock so that the number of revolutions made by the test-bar in any given time can be determined.

Description of Electrical Plant for Operating Experimental Lathe.

(*See* Plate 36.)

The lathe is driven by means of two direct-current motors, one arranged for the main drive and the other for operating the feed mechanism. These motors take their power from a motor-generator set situated in close proximity to the machine, and the whole forms a good example of an isolated plant for motor driving.

Two-phase current at 2,000 volts pressure and 50 frequency is received from the Corporation mains and operates a two-phase, 2,000 volt, slip ring induction motor made by the British Westinghouse Co., Ltd., and capable of giving 76 b.h.p. at a speed of 960 revolutions per minute. Direct coupled to this is a 50-kilowatt compound wound dynamo of the same make, generating at a pressure of 220–250 volts. These machines are controlled by means of a two-panel marble switchboard. The alternating current panel contains a two-phase high tension oil break switch, with automatic overload release; a voltmeter capable of reading either the received or the generated pressure; two ammeters; and a two-phase wattmeter, so that the input to the alternating current motor can be observed. The second panel controls the generator, and is arranged with switches and instruments enabling the input to each of the motors to be observed separately. The chief feature of this panel is that a recording wattmeter is inserted in each motor circuit and a permanent record in the shape of a power-time curve is obtained.

The whole of the switchboard and instruments is of Westinghouse manufacture except the voltmeter and the recording wattmeters, which are of Kelvin and White's and Elliott Brothers' makes respectively.

The main driving motor on the lathe is of 40-b.h.p. capacity, made by Messrs. Vickers. It is a 4-pole 220-volt shunt-wound machine with interpoles, and is capable of running at speeds varying from 200 to 800 revolutions per minute, the speed variation being obtained solely by means of a rheostat inserted in the field magnet circuit of the motor. The feed motor is a 4-pole shunt-wound 220-volt 5-b.h.p. motor, also of Vickers' make, and is capable of having its speed varied from 275–1,100 revolutions per minute by shunt regulation as in the former case. An electromagnetic speed indicator is connected by a flexible shaft to each motor.

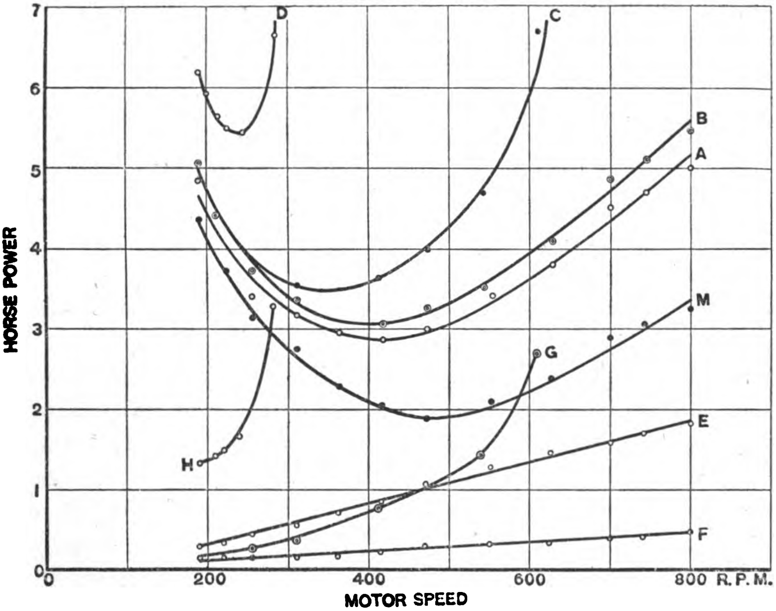
From the generator panel cables are led to two smaller switchboards containing the necessary gear for starting and operating the driving and feed motor respectively. These boards contain an ordinary type of direct current motor starter with no-load and over-load release magnets, two main fuses, and a 23-step rheostat for speed variation; there is also a supplementary rheostat for the driving motor, so that speeds intermediate with those given by the former may be obtained. This supplementary rheostat, having eleven contacts, is connected in series with the main rheostat, the two being so arranged that any one of the contacts of the first rheostat can be used in conjunction with any one of the second. Thus 253 different motor speeds can be obtained for one voltage, these ranging from 200 to 800 revolutions per minute. With the four different methods of driving, the face plate of the headstock, with and without gearing upwards of 1,000 different surface speeds, are available for one diameter of test-bar. The rheostat of the feed motor provides for twenty-three different motor speeds, and these with all the possible changes in the feed-gear boxes give upwards of 700 different feeds (travel per minute) for one voltage.

Measurements of Lathe Efficiency.

Experiments were made on this lathe to determine the various losses which occur in the driving motor, headstock gearing, etc., when the lathe runs without cut under the various possible conditions of speed, etc., and also the motor input, useful power, and efficiency when cutting at a given speed for both the driving and the feeding parts of the lathe.

Fig. 46.

POWER ABSORPTION
CURVES WITHOUT CUT.



The relation between the various power losses and the motor speed is indicated in Fig. 46. Curve M represents the case of the motor running light, the horse-power being the motor input (electrical), this being obtained by readings from the switchboard instruments. The fall in the power required with an increasing rate of revolution between 200 and 500 revolutions per minute is due mainly to the reduction in the magnetization current (to produce the weakened magnetic field) being greater than the increase in the armature current required to cover the increase in the mechanical frictional losses in the bearings, etc., due to the speed increase. Beyond 500 revolutions per minute the latter is much greater than the former; hence the rise in the curve for this speed range.

Curve A is the corresponding curve for the motor and headstock gearing without the driving spindle and face-plate. It was found that the power lost was practically the same for each of the three sets of headstock gearing, provided that the driving spindle and face-plate were not in motion. Curve E, which represents the difference between M and A, gives the net power lost in the gearing only at the different motor speeds.

Curves B, C, and D are the corresponding curves for the motor, headstock gearing, driving spindle, and test-bar without cut. These curves represent the three sets of gearing as follows:—

Curve B: Double Gear Slow . . . . . 1 : 40
„ C: Double Gear Quick . . . . . 1 : 12·5
„ D: Single Gear . . . . . . 1 : 3·96

Curves F, G, and H represent the net losses due to the motion of the test-bar and driving-plate.

To determine the horse-power developed at the nose of the tool under a cut, brake-load tests were made on the lathe with different loads, at different motor speeds, and with the different sets of headstock gearing in action. The conditions of these tests were arranged so that, as nearly as possible, they corresponded to actual cutting conditions. The form of brake used is shown in Fig. 47. The brake-drum was mounted directly on a test-bar which was run in the ordinary way, being driven from the face-plate by dog-chucks. The length of the arm of the brake was 45 inches, and the pillar carrying the knife-edge rested on the platform of a 20-cwt. weighing machine. The brake horse-power was calculated by means of the formula:

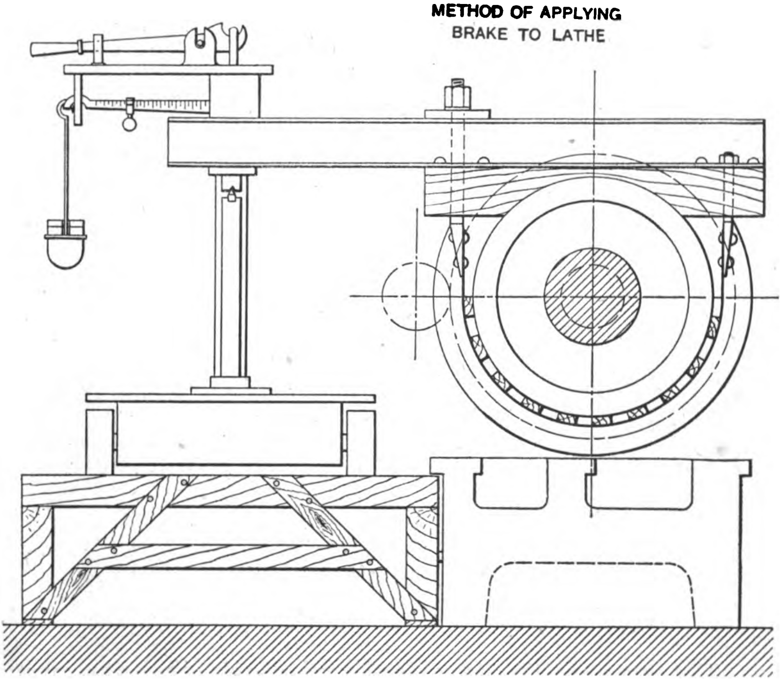
$$\text{B.H.P.} = \frac{2\pi \times 45}{12 \times 33{,}000} \times PN = \frac{PN}{1{,}400} \quad . \quad . \quad (19)$$

P and N being the load in lb., and the revolutions per minute of the test-bar respectively.

From the data of these tests an input curve was drawn from which the output or b.h.p. for any input could be obtained. This curve was used in connection with the actual cutting tests to determine the h.p. developed at the nose of the tool corresponding to each input as obtained from the switchboard instruments.

In the cutting tests, in which the cutting speed was 50 feet per minute, the feed was obtained independently from the feed motor, four different average feeds being adopted, as follows: 0·0185 inch, 0·0551 inch, 0·1417 inch, and 0·1880 inch per revolution of the bar. These are the actual feeds, their values having been obtained by means of actual measurement and calculation. The depths of cut were three in number, as follows: $\frac{1}{8}$ inch, $\frac{1}{4}$ inch, and $\frac{3}{8}$ inch.

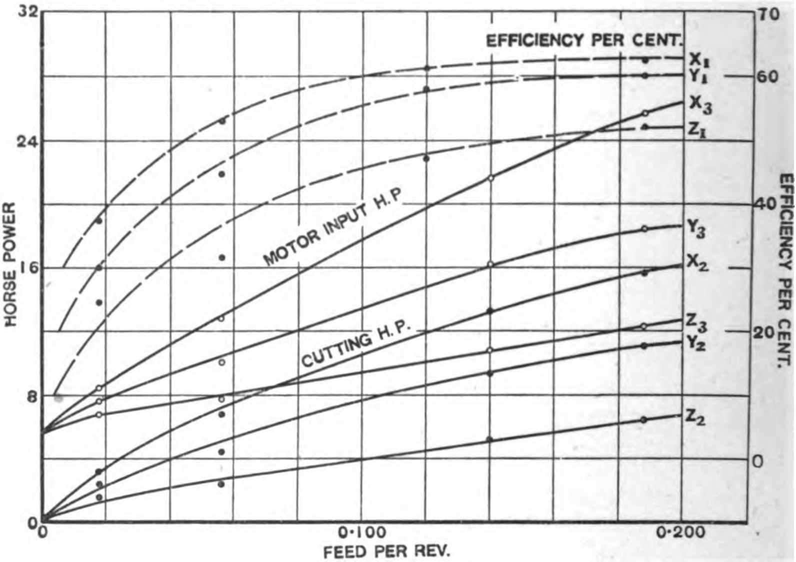
Fig. 47.



The net feeding power in each case was obtained by taking the difference between the motor input, with the cut in, and with the tool withdrawn, respectively, the slide-rest being in motion in each instance. This difference may not be exactly the power required to propel the slide-rest against the resistance due to the cut only, but it is sufficiently close for all practical purposes.

Fig. 48.

MAIN DRIVE CURVES.



The curves in Fig. 48 give the relation between the gross main-driving motor input X_3, the net cutting power X_2, and the overall main-drive efficiency X_1.

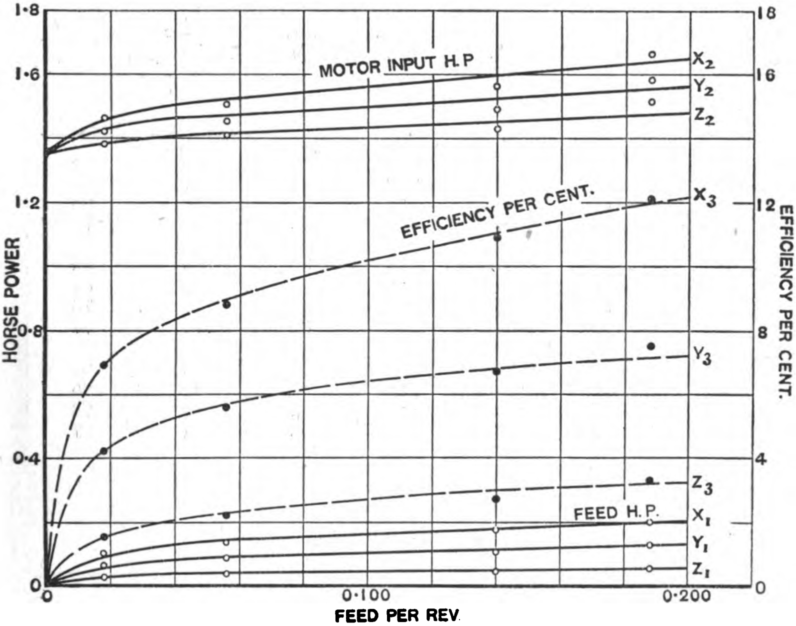
The curves in Fig. 49 give the corresponding relation between the gross feed-motor input, the net feeding power, and the overall efficiency.

The curves X are for the $\frac{3}{8}$ inch depth, Y for the $\frac{1}{4}$ inch depth, and Z for the $\frac{1}{8}$ inch depth.

In the case of the main-drive curves $X_1 = \frac{X_2}{X_3}$, ... while for the feed curves $X_3 = \frac{X_1}{X_2}$ ....

Fig. 49.

FEED CURVES.



LATHE EFFICIENCY TEST RESULTS.

(1) *Main Drive.*

Depth of Cut.	Feed per Rev.	Motor Input.	H.P. at Tool.	Overall Efficiency.	Motor Efficiency.	Lathe Cutting Efficiency.
inch.	inch.	H.P.		Per cent.	Per cent.	Per cent.
⅛	0·0185	6·81	1·5	25	56	45
,,	0·0551	7·70	2·4	31	58	53
,,	0·1417	10·84	5·2	47	69	68
,,	0·1880	12·33	6·4	52	72	72
¼	0·0185	7·59	2·3	30	58	52
,,	0·0551	9·95	4·4	44	66	67
,,	0·1417	16·20	9·4	58	76	76
,,	0·1880	18·35	11·0	60	78	77
⅜	0·0185	8·49	3·1	37	60	62
,,	0·0551	12·78	6·8	53	71	75
,,	0·1417	21·80	13·2	61	80	76
,,	0·1880	25·70	15·8	62	81	77

(2) *Feed Drive.*

Depth of Cut.	Feed per Rev.	Motor Input.	Feed.	Overall Efficiency.	Motor Efficiency.	Feed Efficiency.
inch.	inch.	H.P.	H.P.	Per cent.	Per cent.	Per cent.
⅛	0·0185	1·38	0·02	1·5	45	3·3
,,	0·0551	1·40	0·03	2·1	46	4·6
,,	0·1417	1·43	0·04	2·7	47	5·8
,,	0·1880	1·51	0·05	3·3	48	6·9
¼	0·0185	1·42	0·06	4·2	46	9·2
,,	0·0551	1·45	0·08	5·5	47	11·7
,,	0·1417	1·49	0·10	6·7	48	14·0
,,	0·1880	1·58	0·12	7·6	49	15·5
⅜	0·0185	1·46	0·10	6·9	47	14·7
,,	0·0551	1·50	0·13	8·7	48	18·2
,,	0·1417	1·56	0·17	10·9	49	22·0
,,	0·1880	1·66	0·20	12·1	50	24·2

APPENDIX II.

Physical Properties of Test-Bars.

(*a*) *Test-Bars for Carbon-Steel Tool Tests.*

Letter of Identification.	Breaking Load in tons per sq. inch.	Elongation per cent.	Compressive Load in tons per sq. inch.
W	24·8	28·8	74·8
X	33·5	21·7	90·0
Y	39·5	23·3	106·8
Z	51·2	9·3	128·0

(*b*) *Test-Bars for High-Speed Steel Tool Tests.*

Letter of Identification.	Breaking Load in tons per sq. inch.	Elongation per cent.	Compressive Load in tons per sq. inch.
A	27·2	28·4	81·2
B	33·5	21·7	90·0
C	50·5	12·0	126·4

APPENDIX III.

CHEMICAL COMPOSITIONS OF TEST-BARS.

(*a*) *Test-Bars for Carbon-Steel Tool Tests.*

Letter of Identification.	Carbon.	Silicon.	Manganese.	Sulphur.	Phosphorus.	—
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	
W	0·23	0·027	0·45	0·025	0·025	Mild Steel.
X	0·39	0·075	0·50	0·030	0·038	Medium Steel.
Y	0·54	0·053	0·60	0·032	0·040	Hard Steel.
Z	0·82	0·030	0·36	0·032	0·040	Very Hard Steel.

(*b*) *Test-Bars for High-Speed Steel Tool Tests.*

Letter of Identification.	Carbon.	Silicon.	Manganese.	Sulphur.	Phosphorus.	—
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	
A	0·29	0·100	0·42	0·037	0·028	Mild Steel.
B	0·39	0·075	0·50	0·030	0·038	Medium Steel.
C	0·60	0·249	0·83	0·053	0·030	Hard Steel.

APPENDIX IV.

Values of K *in expression* (9).

T = Tensile strength.	$K = \{(65 - T) \times 0{\cdot}207\}$.
25	8·28
30	7·24
35	6·21
40	5·17
45	4·14
50	3·10

APPENDIX V.

POWER TESTS.

HIGH-SPEED STEEL.

Bar A.

Tensile Strength: 27·2 tons per square inch.

Area of Cut.	Associated speed. S.	Cubic inches removed per hour.	Net Power h.p.	Cubic inches per h.p.-hour.	
inch.					
$\frac{1}{8} \times \frac{1}{8}$	60	674	5·95	113·3	113·0
" $\frac{1}{12}$	80	599	5·04	118·9	
" $\frac{1}{20}$	112	504	4·49	112·3	
" $\frac{1}{30}$	156	460	4·28	107·5	
$\frac{3}{32} \times \frac{1}{8}$	68	572	5·07	112·8	113·2
" $\frac{1}{12}$	88	493	4·52	109·1	
" $\frac{1}{20}$	129	427	3·97	107·5	
" $\frac{1}{30}$	176	393	3·19	123·2	
$\frac{1}{16} \times \frac{1}{8}$	78	438	3·71	118·0	121·2
" $\frac{1}{12}$	100	374	3·02	123·9	
" $\frac{1}{20}$	142	319	2·73	116·9	
" $\frac{1}{30}$	196	282	2·24	125·9	

Average cubic inches per h.p.-hour = 115·8.

Power Tests (*continued*).

Bar B.

Tensile Strength: 33·5 tons per square inch.

Area of Cut.	Associated speed. S.	Cubic inches per hour.	Net Power h.p.	Cubic inches per h.p.-hour.	
inch.					
$\frac{1}{8} \times \frac{1}{12}$	67	501	4·40	113·9	112·6
,, $\frac{1}{20}$	92	413	3·73	110·8	
,, $\frac{1}{30}$	130	390	3·45	113·1	
$\frac{3}{32} \times \frac{1}{12}$	74	416	3·70	112·4	112·4
,, $\frac{1}{20}$	106	357	3·25	109·8	
,, $\frac{1}{30}$	144	324	2·82	114·9	
$\frac{1}{16} \times \frac{1}{8}$	62	349	3·20	109·1	112·8
,, $\frac{1}{12}$	83	311	2·85	109·1	
,, $\frac{1}{20}$	118	266	2·35	113·2	
,, $\frac{1}{30}$	164	245	2·04	120·0	

Average cubic inches per h.p.-hour = 112·6.

POWER TESTS (*continued*).

Bar C.

Tensile Strength: 50·5 tons per square inch.

Area of Cut.	Associated speed. S.	Cubic inches per hour.	Net Power h.p.	Cubic inches per h.p.-hour.	
inch.					
$\frac{1}{8} \times \frac{1}{12}$	29	217	2·67	81·3	80·7
,, $\frac{1}{20}$	43	192	2·38	80·7	
,, $\frac{1}{30}$	56	165	2·06	80·1	
$\frac{3}{32} \times \frac{1}{12}$	35	196	2·43	80·7	80·1
,, $\frac{1}{20}$	49	162	2·03	79·8	
,, $\frac{1}{30}$	64	143	1·79	79·9	
$\frac{1}{16} \times \frac{1}{8}$	33	185	2·28	81·2	81·0
,, $\frac{1}{12}$	39	146	1·83	79·8	
,, $\frac{1}{20}$	55	122	1·48	82·4	
,, $\frac{1}{30}$	75	108	1·34	80·6	

Average cubic inches per h.p.-hour = 80·6.

APPENDIX VI.

SHEFFIELD UNIVERSITY.

ENGINEERING DEPARTMENT.

Lathe-Tool Test Sheet.

Date of Test.............................. No. of Test....................................

No. of Tool................................ Size of Tool..................................

Shape of Tool Nose......................

Angles of Tool Nose:—

Clearance: Front.....................; Side..............................

Top Rake: „ ....; „ ....

No. of Test Bar........................... Diameter of Test Bar.......................

Time of Start............................ } Duration of Test...........................
„ „ Finish........................... }

Revolution Counter at Start.................. } Total Revs.........................
„ „ „ Finish .... }

Surface Speed, in Feet per Minute..................................

Depth of Cut.......................... Feed per Revolution.........................

Volts: Light.............................. }
Load.............................. } Net Power.........................k.w.
Amps: Light............................ } „ „ ....h.p.
Load.............................. }

Headstock Gearing....................................

Motor Rheostat Contacts..............................

Discussion in Manchester, on Thursday, 20*th November* 1913.

The **President** said he was quite sure that it would be the wish of the Meeting to accord a hearty vote of thanks to the authors for their interesting Paper, which had been so ably presented by Professor Ripper.

The vote of thanks was carried by acclamation.

Mr. **Christopher W. James** said the Paper was so complete and so full that he had not been able thoroughly to digest it, but most of the experiments appeared to have been made upon small cuts—not comparable with the cuts which had to be dealt with in actual practice on heavy forge or gun work. He would like to know whether the authors had made any experiments upon heavier sections of cut, and whether their conclusions still held good. He himself had found, in making experiments on the shearing strength of material, that the shearing stress per square inch did not increase directly as the thickness of the material, and, as the cutting action of a tool in a lathe was to a great extent a shearing action, it occurred to him that possibly the same effect might take place. In the Paper the experiments showed that the section of the tool made a very material difference to its capacity; that is to say, if one had a half-inch-square tool it would turn off a certain amount of material, whereas a 3-inch-square tool would turn off a great deal more without showing signs of distress, so that the capacity of the cutting-tool would appear to depend almost entirely on its capacity for absorbing and dissipating heat and maintaining a temperature within the limits of which it could work.

He did not know whether it was expressly stated in the Paper that all these tests had been made with a tool working dry, but it appeared to be so; and therefore he thought that their quantitative results were not what one would expect to be compelled to adhere to in workshop practice and under profuse lubrication—that is to say, jets of water or any heat-conveying fluid in large quantities and at high velocities. He thought that the output of the tools would, under such conditions, be largely increased, so that the limits given by these various experiments would in those cases be exceeded.

Mr. **Alfred Saxon** thought it was fitting that this Paper should be presented in Manchester before being read in London. With regard to the first paragraph (page 1067), "The question of the definite measure of the output of work, or of the removal of material, of which lathe-tools are capable, is one about which there is very little information readily available," he must express his surprise at this statement, because the first important experiments with tool-steel in this country were made at the Manchester School of Technology in the year 1903, under the supervision of the Council of the Manchester Association of Engineers—their only research work up to the present. Dr. Nicolson, to whom he was very glad Professor Ripper had so feelingly referred, and his staff, carried out the experiments and obtained some very reliable and valuable data. Two years ago those experiments were supplemented by a Paper read by Mr. Dempster Smith, so that if anyone had read those voluminous reports on tool-steel he would not think the authors were justified in saying that there was very little information available.

The experiments made in the laboratory of the University of Sheffield had been on a smaller scale than those which were conducted in Manchester. For instance, the Manchester Committee laid down the condition that tool-steels of 1¼-inch square were to be supplied for testing, and they did not confine themselves to one make of steel, so that in their tests they were leaving the field open to the best steel-makers. Eight firms sent in their samples for testing, and all were tested. He found that in Professor Ripper's tests only ten tools were used in the carbon-steel tests, and those were so small in section as ¾-inch by ½-inch and 6 inches long. Mr. James had referred to the fact, which the authors stated in the Paper, that these tests were taken without lubrication of the cutting edge of the tools. He (Mr. Saxon) stated that, with regard to carbon-steel particularly, without lubrication the tests were not reliable, so far as workshop practice was concerned, and the data from that point of view would not be quite so useful.

(Mr. Alfred Saxon.)

The authors had opened up new ground, and had obtained valuable results and data. Still, unless they continued the tests further and used lubrication, he did not think that they would have given that workshop test to carbon-steel that they might have done.

With regard to the high-speed tool-steel tests, the Meeting was indebted very much to the authors for the further series of tests on different sizes of tools, which they had made to determine the relative effects of area of tool-steel section upon the possible output. He thought the authors had scored a point with regard to that part of their Paper, the results of which were tabulated on page 1114. He was in general agreement with the summary of their conclusions with regard to depth of cut and other points, which Professor Ripper had elaborated that evening.

Mr. H. W. **Allingham** said he thought the Paper certainly showed a move in the right direction, namely, an effort to obtain more accurate knowledge of the action of cutting tools. In the results obtained, however, he was much disappointed, for the reason that he felt the authors had not really added very much to the knowledge published by Mr. F. W. Taylor and Dr. Nicolson. As the audience, of course, was aware, Mr. Taylor conducted all his experiments entirely for what he could get out of them commercially, and after obtaining formulæ he and his co-worker—Mr. Carl Barth—placed them on slide-rules, with a view to enabling them to be made use of commercially by practical engineers. Unfortunately, those slide-rules were not obtainable by anybody except people who were systematized by Mr. Taylor and those who had worked with him, which rather depreciated the value of the results obtained, from a practical point of view. However, he would suggest that Professor Ripper would be doing a great service to engineering if he were to continue his researches with the following question foremost in his mind: "What steps must be taken in the ordinary engineering factory to enable quick and certain use to be made of the scientific data being obtained?" Professor Ripper's results, however, went no further than other people's published results, and generally speaking they were incapable of immediate application to practice. Mr. Taylor's and Dr. Nicolson's results had not been applied to any extent either in this country or in America, simply because the actual application in practice of theoretical results of this kind was difficult, seeing that they did not take into consideration all the variables in the shop, such as spring, the hardness of every casting that happened to be delivered on the floor, and so forth. For that reason it seemed to him (Mr. Allingham) that they were all right as theoretical curves, but, so far, they were not in a condition to make much use of.

If data, enabling the productive powers of metal-cutting tools to be made known, were to be supplied for the use of engineers in general, he still thought it was necessary that those experiments should be made by the technical schools, because a commercial firm that made experiments would have to keep the results more or less to themselves for commercial reasons. They could not afford to give all their competitors the results.

He had had for some little time past a somewhat unique opportunity of finding out what results could be obtained by studying a battery of screw-machines. In this case they had a number of tools working in quick succession, some even at the same time, and the variables of speed and feed were complicated by many other factors. So far as he was aware, no laws or curves were at present available showing the effect of varying the variables on the automatic screw-machine. The problem was found to be so large that a special room was set aside, quite apart from the manufacturing department, in which about half-a-dozen machines of different sizes were provided with facilities for conducting experiments on a semi-scientific basis. They were not run as scientifically as Professor Ripper's experiments, and it was not claimed that they were carried to their logical conclusion, owing to the short time that the experimenters had been engaged upon them. There were two men working the machines, in charge of an engineer specially engaged from the National Physical Laboratory to conduct the experiments on a scientific basis, and after twelve months' work in this room the results had been put into practice. At the same time as the cutting

(Mr. H. W. Allingham.)

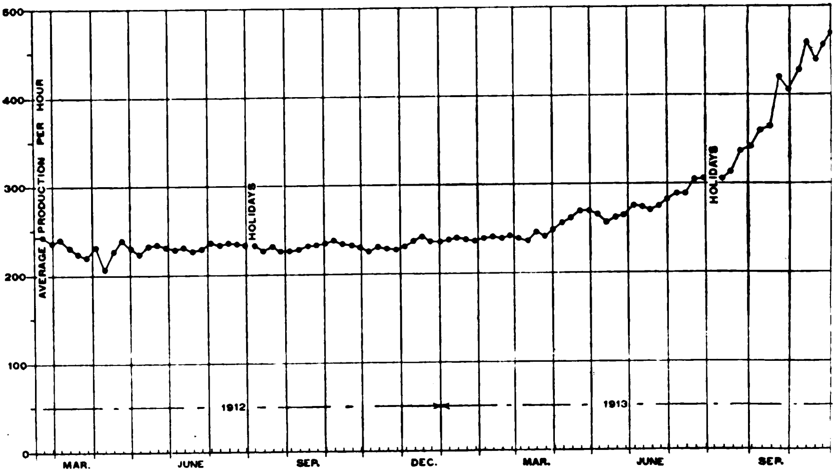
tests, wear tests of the articles produced were conducted to find out the effect of different roughnesses, as a result of which very exact standards for inspection of parts had been instituted.

The question of finish was one of the most important to engineers. If the machine was merely speeded up until the tool was collapsing, a bad finish was obtained, and the quality of the work would go down; so that the practical engineer was limited by keeping the quality as first class as might be necessary. As an example of the results, Fig. 50 illustrated the average output of 105 automatic screw-machines, which were all of the same size, mostly made by Brown and Sharpe. In 1912 the average hourly output of pieces off these 105 machines was 230. It was in November 1912 that the experimental department was installed, and gradually the results of those experiments were put into service, and for the week ending 5th November the average hourly output of the 105 machines had reached 490 pieces. That was an increase of practically 100 per cent., as the direct result of considering the

Fig. 50.—*Automatic Turning Department.*

Cycle size: Bush, Roller and Stud Turning.

Output of 105 Machines.



problem from the scientific standpoint. A fortnight ago this experimental department was disbanded, not because the experiments had come to a conclusion, but because the money expended to run it would not be returned in a further increase in output. Supposing they had expended £800 on these experiments—it was about that amount—and they had obtained certain results. They might spend another £800 and their output might be increased a further 5 per cent. It was not worth it, and therefore they had discarded it. That was one of the reasons why they had to look to the technical schools to carry the experiments to a logical and complete conclusion.

There was one point in connection with these experiments that he might mention which, he believed—he did not know for certain —was rather new. Machine reamers used for finishing small holes in mild-steel bars were now standardized to a top-rake of 20°, just like a turning tool. He believed it was the general practice throughout the world to use no top-rake, or only a very small top-rake on reamers, but they were now being standardized to 20°, and he would recommend engineers to try what the effect of making a reamer like a cutting tool would be.

Works managers in this country, with whom he had discussed the subject of Mr. Taylor's "scientific management," disdained it, and thought it was an absurd refinement, that it had no practical value, and that it was not worth going on with. He wished to appeal to them to allow experiments to be conducted, or to persuade their workmen to allow the experiments to be conducted, in their own shops. He believed they would find ultimately that results would be obtained which were very astonishing. The fact that he had taken, as an example, a department with 230 automatic machines in it must not be regarded as suggesting that only very large batteries of machines were capable of being studied economically. Of course, the more machines there were of the kind, the more scientifically it was worth while to study them. Similar studies were being taken in hand at the present time for as small a number of machines as half a dozen, such as boring mills of various sizes, lathes, milling machines, etc., and in every case

(Mr. H. W. Allingham.)

noticeable results were being obtained, even without going to the point of plotting curves showing the absolute maximum possible output from the tools.

In general, the experiments that his firm had conducted had shown that the modern speeds were too high, and that the areas of chip were too small. He quite agreed with the authors that the area of the chip should be as thin and as deep as possible, but where one had a certain amount of metal to come off, say, a quarter of an inch, it was not generally feasible to start with a very long cutting angle. It was preferable, he thought, to use a standard tool and to take the biggest chip and the biggest feed that the machine would take. As a rule, they had reduced the speeds and increased the feeds. All the results had been obtained by carefully considering the published laws of such experiments as those of Mr. Taylor and Dr. Nicolson, and seeing how other laws could be determined, and working very largely from the theoretical end. They had also standardized the lathe tools practically to those shapes that Mr. Taylor has recommended. He thought it was a pity that the authors had not tested the tools for the correct cutting angle for hard steel and for soft steel. They used a tool with a 23° rake on hard steel, and he ventured to suggest that the authors would have obtained very much better results if they had used a tool with much less top-rake.

In conclusion, he would emphasize that technical schools must be looked to for the published results of experiments of this type, but the experiments must be conducted with the question always in view: "How can the data be easily and quickly made use of in a practical workshop?" He would appeal to engineering firms not necessarily to wait for the technical schools to make the scientific experiments, but to do much more themselves in this direction than had been done in England in the past. Finally, he wished to thank Messrs. Hans Renold, Ltd., for allowing him the opportunity of giving such details as he had given this evening.

Mr. E. G. HERBERT (Manchester) said he had a special claim to the patience of the Meeting, because, as Professor Ripper had informed them, it was owing to some heterodox statements to which he (the speaker) must plead guilty, that he was induced to commence the enormous task which had been described in the Paper before them. He thought that if his work had not led to any other results, he could rest satisfied that it was well worth undertaking if it had produced the present Paper. He would like to express his high appreciation of the Paper, and especially of the manner in which it was worked out, and the lucid methods of bringing the utmost amount of information out of all the tests. When one remembered that each of the little dots, so freely scattered through the diagrams, represented a test of perhaps an hour or two hours' duration, and that they only represented a few out of the many experiments which were made, one could readily imagine how many months of strenuous work this Paper represented.

The first point that struck him, on reading the Paper, was that all the tools were ground to the same angle. The previous speaker said that might not be correct workshop practice, but it struck him (Mr. Herbert) in a very favourable light. The Manchester tool experiments contrasted with these in this respect, that all the tools were ground at different angles. He believed there was as much as 27 degrees between the angles of the various tools which were tested and compared together, without any account being taken of the important influence of the cutting angles on the results. He thought at the time it was extraordinary. A year or two ago when he called upon Professor Schlesinger in Charlottenburg, he was surprised to find that the Professor also used tools of different angles, and he gathered that it was left to the steel-maker to determine what was the best angle for his particular steel. He was quite sure that if one asked half-a-dozen steel-makers or half-a-dozen workmen what was the proper angle for a tool, a different answer would be given in each case, but he thought Professor Ripper had done very well in reducing the number of variables in his tests and using tools of the same shape.

As regards the method of measuring the bluntness of tools and using the standard bluntness as a limit to the test, that was a

(Mr. E. G. Herbert.)

principle which he had advocated and practised for a number of years. He could not, however, think that the actual method adopted by Professor Ripper was the ideal one. Subject to correction, he would say that the width of the worn surface on the top of the tool depended to some extent on the thickness of the chip impinging on it, which caused the wear.

Another and even a more serious objection to Professor Ripper's method appeared to be, that in order to carry it out the tool must be repeatedly taken from the tool-holder and measured under a microscope. As the authors had pointed out, the heating effect upon the tool was cumulative; that is to say, heat was accumulated in the shank of the tool, and this was an important factor in preventing the evolution of heat at the point and causing an ultimate breakdown, so that the removal of the tool at intervals appeared to introduce an element of uncertainty, apart from the difficulty of putting the tool back in exactly the same place. In some experiments by Professor R. Poliakoff to which he would refer later, a standard bluntness was used as a limit to the test, and the method employed depended upon the fact that the tool "lost its cut," as one said in the shops, as it became blunt. The lathe was set to slide parallel, and an indicator was arranged so that it showed any variation in the diameter of the bar. As the tool wore, the diameter of the bar increased slightly, and when it had increased to the standard amount the test was stopped. That allowed the measurements of wear to be taken continuously without removal of the tool, and it seemed a preferable method to that employed by Professor Ripper.

With regard to the conclusions of the authors (page 1091), the second conclusion was, that the durability was in all cases some function of the reciprocal of the cutting-speed, and the fourth was that certain curves tended to become horizontal, suggesting that there was, in each case, a definite cutting-speed below which the tool would last practically an indefinite length of time. He took it, therefore, that the second conclusion was based upon a suggestion of what would have happened at a speed which was not tested. It seemed to him rather a precarious foundation on which to base a general statement, and on which to contradict other statements which were based upon experience. If the curve on Fig. 51 was compared with those on page 1081, one would see that it was a very similar type of curve, and one might be tempted to conclude, as Professor Ripper did, that as the curve tended to become horizontal at the lower speeds, if the speeds were still further reduced the tool would last indefinitely, "more or less," as he said. What a good thing it would be for them if tools would last indefinitely! He carried the speeds lower, and found what was shown on Fig. 52. The durability attained a maximum, and then declined. This was not an isolated instance. Every tool that he had tested, without exception, had shown a similar phenomenon when the speed had been taken low enough. Now, he was not going to assert that if Professor Ripper had reduced his speeds lower he would have found this phenomenon. He wished to be very clear on this point, because it was one on which there had been some misunderstanding. He had always endeavoured to make it clear that this phenomenon, of increasing durability as the speed was increased, could only take place when the cutting point of the tool was practically cold. Under the conditions of Professor Ripper's tests, it could not possibly take place, because he was using a cut which was not suitable. As a matter of fact, the smallest cut Professor Ripper used in the experiments to which he was referring was twenty-seven times as heavy as the cut used on the tool-steel testing-machine (which was quite an ordinary finishing cut). Further, he was not using water-cooling; so that in order to get the tool-point practically cold with

Fig. 51.

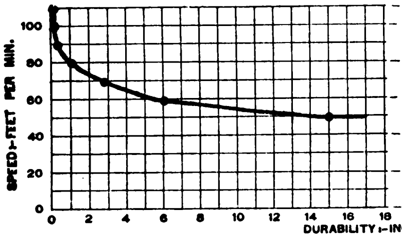
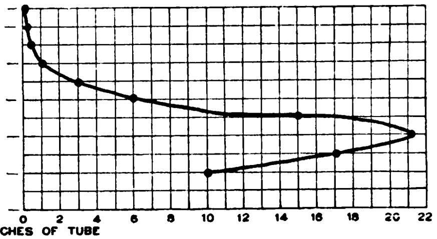


Fig. 52.



(Mr. E. G. Herbert.)

the cut he used, he would have had to reduce his speed beyond anything that one encountered in the workshop, and it was possible that some other factors would have supervened to prevent this phenomenon occurring. Had he used a small cut with water-cooling, he would have found the phenomenon he had called attention to.

He could not help remarking here that Professor Ripper seemed to have missed a great opportunity in his experiments. He had expended an enormous amount of time and patience, and no doubt money, in carrying out these experiments in a field which had been, he thought, fairly completely surveyed already. Another field equally accessible, equally important, and unexplored he had entirely neglected. How much of all the tool-steel which was produced in Sheffield was used in finishing cuts? Was it a quarter, or a third, or a half? Generally speaking, there was a finishing cut for every roughing cut, and the finishing cut was the more important, because it took longer, owing to the finer feed, and because the slightest blunting of the tool injured the finish of the work. What was the behaviour of the steel under finishing cuts? One might study the results of Dr. Nicolson and Mr. Taylor, and would find nothing about it.

Then there was the question as to which was the best steel for finishing cuts. Was it the same steel which would give good results under a heavy cut? Again, there was a complete silence; they had not heard of finishing cuts. One would think that engineers had nothing to do but to thin down monstrous propeller-shafts. Finishing tools would not last indefinitely. One of the reasons which might have deterred experimenters from that subject was the fact that finishing tools were not generally carried to a breakdown, and therefore a breakdown test was not applicable. The tool was sharpened as soon as it became a little dull and did not produce a good finished surface; but Professor Ripper and his collaborator had overcome this difficulty by their method of measuring bluntness, which was, of course, equally applicable to finishing tools as to roughing tools. He thought if they had used that method or the other method which, he thought, was preferable and which he had just described, they would have come to some very interesting results.

This matter of increasing durability with increasing speeds was, he thought, first of all brought out by the tool-steel testing-machine. It had been confirmed by a great deal of evidence in the workshop, in his own and other workshops, but it no longer rested there. Recently Professor R. Poliakoff, of the Imperial Technical Institute of Moscow, had been carrying out a series of lathe tests, and he understood the results were to be published. They had been sent to the speaker, he did not think confidentially, but still he thought he was not justified in giving them away entirely, though he might just indicate the nature of them. They were made on an ordinary lathe, and they included finishing cuts; some of them considerably heavier than usual on the tool-steel testing-machine. The tests were limited by the bluntness of the tool in the manner he had described, and the speed durability curves, which were in his possession, showed, Fig. 53, in every case this same phenomenon to which he had called attention, namely, the increasing durability at increasing speed. He thought, therefore, Professor Ripper should modify his second conclusion by a clause to the effect that "this conclusion does not apply to the important range of cutting conditions which the authors have left unexplored."

Fig. 53.

Prof. Poliakoff's Lathe Tests.

Depth of Cut 0·12 mm. Feed 0·35 mm.
Full line = Square Nose Tool.
Dotted line = Round Nose Tool.

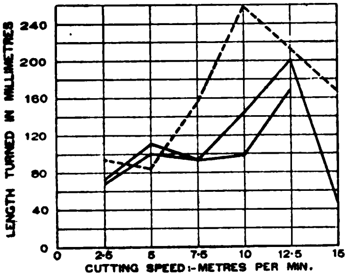
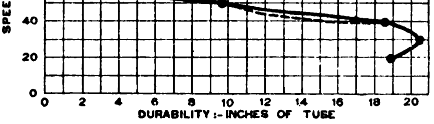


Fig. 54.—*Durability of Tool.*

Fourteen observations plotted.



(Mr. E. G. Herbert.)

Even then, he was afraid, he could not quite agree with the second conclusion. If the Paper had been read a year ago, he would have said that with the conditions used by the authors of the Paper—that is to say, fairly heavy cuts and dry cutting—they could not have found an increasing durability with increasing speed, but recently quite a number—not a large number, but still a considerable number—of cases had occurred where on a test on a high-speed-steel tool on the testing-machine, durability had increased with increase in cutting speeds. As the speed was increased the durability went down and then came up again, and then went down and became the minimum. The curve on Fig. 54 was well within the range of Professor Ripper's experiments. The blue chip period began at about 70 feet per minute, and at 140 feet per minute the chips were red-hot in the tool-steel testing-machine, so that the temperature of the tool must have been similar to what it was in a great many of these experiments.

A Member: Was that with a light finishing cut?

Mr. HERBERT: Yes.

The Member: Was it lubricated?

Mr. HERBERT: No, it was dry in this case. This phenomenon was somewhat exceptional with a dry cut. Whether the property was possessed by Professor Ripper's tools or not, he could not say. If his tools did possess it, he thought it was quite possible that Professor Ripper would not have discovered it, without any disrespect to him, and for the reason that the curve, Fig. 54, was produced as the result of observations at fourteen different cutting speeds. Professor Ripper's speed durability curves were produced as a result of observations at four cutting speeds. He had just indicated what would have happened if he had taken four cutting speeds and formed his conclusion from them. He would have got four dots, and drawn a sweeping curve through them. (*See* dotted curve, Fig. 54.)

As regards the relative importance of feed and depth of cut on the durability of the tool, he agreed completely with Professor Ripper, and it was always a matter of some surprise to him that Dr. Nicolson and his collaborators should have held the contrary view, that they were equally important, because some of the results of the Manchester experiments bore the clearest evidence of the truth of the contrary view taken by Professor Ripper. On Fig. 29 (page 1099) it would be seen that there were two series of curves, the constant-feed curves and the constant-depth curves, which were curves of different orders; that is to say, they crossed each other. Now what would be the effect of increasing the feed and the depth alternately? Obviously, we would first travel down one of the curves belonging to one order, and switch off at an angle on to one of the other curves, and then switch back, and so would get a somewhat zigzag curve. It might be within the recollection of many present that that was exactly what took place in the Manchester experiments on cast-iron. The feed and depth of cut were increased alternately, and a zigzag curve was produced, as could be seen in the Transactions. He thought that gave the clearest evidence of the truth of the view propounded by Mr. Taylor and confirmed by Professor Ripper.

In the year 1909 he (Mr. Herbert) read a Paper before the Manchester Association of Engineers, in which he ventured on a little theorizing as to the law governing the evolution of heat in a cutting tool, and he came to the conclusion that the cutting speed for constant durability of the tool should be in inverse proportion to the cube root of the thickness of the chip. This was called in question, and, in his written reply to the discussion on the Paper, he carried the theory a little further and came to the following conclusion. He worked out what he called "the cube law of cutting speeds," that is to say, for constant durability, the cutting speed was inversely proportional to the cube root of the thickness of chip, multiplied by area of cut. This cube law he restated in two Papers read before the Iron and Steel Institute in 1910 and 1912, from one of which Professor Ripper quoted in his opening remarks. It was with considerable interest that he saw Professor Ripper's Formula

(Mr. E. G. Herbert.)

No. 12 (page 1109) was his own "cube law." In place of thickness of chip, Professor Ripper had feed, but as pointed out in the Papers referred to above, the feed and thickness of chip were generally proportional. They ceased to be proportional only when the depth of cut was small, and considerably less than the radius of the nose of the tool. In that case the formula ceased to apply, unless the actual thickness of chip was used instead of the feed. It would be a matter of interest to him personally to know whether Professor Ripper had worked this law out afresh, in ignorance of the fact that it had been already published. He might add that when that law was published he showed that Mr. Taylor's curves obeyed the law in a very perfect manner. He thought it was very gratifying to know that the same law which applied to the results of Professor Ripper's experiments—and, so far as he had had time to test them, it applied very closely indeed—applied also to Mr. Taylor's. The two were linked together by the one law and linked also to the theory of the evolution of heat.

As to Professor Ripper's increment test of tool-steel, he could only say he did not consider it an ideal test, but he thought it was an immense improvement over the old cutting test at one speed. The test at single speed would always hold its own where only one particular class of work had to be done, such as tyre turning. The best test, then, would be to test the tool on the job under working conditions. The best tool was the one which did best. As a test for tools that had to be used under the varying conditions of the workshop, he thought the increment test was as good a test as could be made on an ordinary lathe or, he would say, an extra-ordinary lathe, because a very elaborate provision of speed-control mechanism was required to carry out the test. If he might be allowed to use a simile, he would put it somewhat like this: Supposing one wanted to find the depth of the Atlantic. Somebody came forward and said he could find the depth of the Atlantic. He let down a line and said the depth of the Atlantic was 3 inches or 3 feet, or 3 fathoms or 3 miles, according to the point at which he let down the line. That was the single speed test. But there were two other methods of finding the depth of the Atlantic. One was to sail across the ocean with a lead-line dragging along the bottom, noticing the average position of it, and calling that average position the depth of the ocean. There was another method, which consisted of sailing across the ocean noting the depth at each point, and marking down those depths on a chart, which would show where it was deep and where shallow. That was the method which he preferred, and which he thought the mariner would prefer, but it was a method which could scarcely be carried out on an ordinary lathe, because it involved an enormous amount of work which was quite prohibitive in making commercial tests.

He would like to express his appreciation of the valuable tests on tools of different dimensions. It would have added interest to the experiments if the authors had also shown what was the effect of a small tool in a large tool-holder as against a solid tool of the same section.

Mr. SHIPLEY N. BRAYSHAW said that the authors had done an enormous amount of work, and many members wished they had done more, by varying the angle of the tool and so forth. He (Mr. Brayshaw), for one, commended them for their restraint in this matter. Anybody who had too many variables proved nothing, and he thought that for any good experimental work, the number of variables must be reduced. Professor Ripper's work was obviously so well done, and the results were so consistent, that they must be accepted as accurate and trustworthy, and he had every confidence in them. He did not think the method of testing the wear with a microscope was ideal, but this objection did not apply to the high-speed tools in which the test was automatic.

The curious thing was the divergence between these good and credible results and those obtained by Mr. Herbert. In Mr. Herbert's case the work was equally well and carefully done, and he (Mr. Brayshaw) had equal confidence in it. He thought that it was perfectly possible that both Papers were entirely correct—that Professor Ripper's Paper was correct as far as it went

(Mr. Shipley N. Brayshaw.)

and that Mr. Herbert had explored ground which Professor Ripper had not touched. It was not necessary to refer to Mr. Herbert's machine. It was probably familiar to most of them. Some of the differences between the two investigations were that Professor Ripper's work was always done dry. Mr. Herbert, on the other hand, sometimes used lubrication and sometimes not. He found very great differences between the tool working dry, the tool working with water, and the tool working with oil. They gave entirely different results.

Then, again, Professor Ripper's work was comparatively heavy. It would make some people smile to talk of this being heavy work. It was heavy work compared with Mr. Herbert's. Mr. Herbert was dealing with cuts one-hundredth of an inch—or less—very fine cuts, and it was quite likely that different conditions arose under those circumstances. He noticed that Mr. Herbert, in one of his Papers read before the Iron and Steel Institute in 1912, said that a low-cutting temperature could only occur when there was a combination of low-speed and light cut, and he thought Mr. Herbert proved conclusively that when the temperature of cutting was low enough, then the cutting was inferior, and that it was necessary to speed up to get better results. That condition could not occur easily with Professor Ripper's heavy cuts, because do what one would, even working with water, one would not be able to cool the tool sufficiently. There was a great deal of work that must be finished with fine cuts. Thus, in the case of circular turning tools, taking a long cut but very shallow and turning out those frills that one saw on some automatic machines, doing such work as turning bicycle hubs, the cut though heavy on account of its length was very slight in depth, and he thought that Mr. Herbert's conditions might arise exactly. He believed that it would be in the experience of many—it certainly was in his own experience, and he had tested it—that under some conditions, if the machine was run too slow the tool was dulled. He thought that this had been known by turners in the workshop for a long time. When he (Mr. Brayshaw) was an apprentice at Messrs. Beyer Peacock's, having some difficulty with a tool—Mr. Herbert had not published his results then—a turner told him to run faster, and when he went at a higher speed the tool stood up. He was quite satisfied that this happened often in the workshop, and many turners knew it as a matter of practice, although if one were to ask them about it they would naturally say that the slower one ran, the longer the tool would last. They would say so, and think so, because it seemed such a natural supposition, but in practice they sometimes speeded up to make the tool stand.

He thought that Professor Ripper had proved his points, but he had not disproved Mr. Herbert's points. He was struck with the similarity between a formula worked out by Professor Ripper and by Mr. Herbert, and he was much interested in it. It was Formula 12 (page 1109), namely S, that is the cutting-speed in feet per minute, equals K over the cube root of A × F. K was described on page 1137. A is the area of cut and F is the feed. Mr. Herbert put what appeared to be practically the same thing in a Paper before the Iron and Steel Institute in 1910, No. I, page 225, in this form:—

"For constant durability of the cutting tool, the speed varies inversely as the cube root of the product of area of cut by thickness of shaving." He supposed that in the case of Mr. Herbert's fine cuts, the thickness of shaving would be about the same as the feed. It was very interesting and satisfactory to see that two independent investigators had arrived by different methods at a similar result. He thought that the experiments that had been described in the Paper were very useful, and the members were indebted to Professor Ripper and his colleague for the work they had done and for putting the results before the Meeting—results which might be relied upon fully so far as they went. He hoped the authors would be encouraged to continue their work, for it was by such unselfish research and publication as this that one might hope ultimately to arrive at the truth.

Mr. **Dempster Smith** said that, as carbon-steel tools cut at a low speed and usually gave evidence of fatigue by the cutting edge becoming dull rather than by fusing, the authors had chosen a certain degree of edge-bluntness as affording a measure of the

(**Mr. Dempster Smith.**)

performance of a carbon-steel tool when operating under ordinary working conditions. Evidently this plan had been resorted to after repeated failures to obtain consistently uniform results by running the tool to destruction. Providing the conditions prevailing in practice were obtained in the tests, and the wear of the tool could be accurately measured, such a standard was probably as good as any other. The method adopted for measuring the bluntness was more open to question, as it seemed very difficult to tell with any approach to accuracy, when the bluntness curve terminated on the upper surface and the straight face of the tool began. In determining the standard bluntness, the tool was frequently withdrawn and re-entered after examination, and a cumulative bluntness error would result, due to the cutting-edge being brought into contact with the solid bar.

Cutting Speeds for various cuts when operating with Carbon-Steel Tool on Mild Steel of 27 tons tensile strength.

Traverse.	Cut.	Area.	Authors' $S = \frac{40 \times 0{\cdot}0185}{\sqrt{A}}$	Ordinary workshop practice.
Inch	Inch	Sq. Inch.	Feet per min.	Feet per min.
$\frac{1}{16}$	$\frac{1}{32}$	0·00195	16·74	28·0
$\frac{1}{16}$	$\frac{1}{16}$	0·00390	11·84	21·0
$\frac{1}{16}$	$\frac{1}{8}$	0·00781	8·37	17·63
$\frac{1}{16}$	$\frac{1}{4}$	0·01563	5·92	14·0
$\frac{1}{8}$	$\frac{1}{8}$	0·01563	5·92	14·0
$\frac{1}{8}$	$\frac{1}{4}$	0·03125	4·19	11·0
$\frac{1}{8}$	$\frac{1}{2}$	0·0625	2·96	8·8
$\frac{1}{4}$	$\frac{1}{2}$	0·125	2·09	7·0
$\frac{1}{4}$	$\frac{3}{4}$	0·1875	1·71	6·2
$\frac{1}{4}$	1	0·25	1·48	5·6

Having regard to the fact that in many of the trials a small pile of shavings adhered to the extreme outer edge, thereby protecting it and indicating that the edge was not subjected to the same duty as the edge of tools in trials where this did not occur, the regularity of the results was remarkable.

The values for carbon-steel tools given by the authors' expression, namely $S = \frac{(67 - T)\, 0{\cdot}0185}{A^{\frac{1}{3}}}$ were extremely low in comparison with those obtained in practice when operating on ordinary mild steel. This would be observed from the Table (page 1160).

The cutting speeds for other qualities of steel were also low, and it appeared that the authors' values required to be multiplied by 2 or 3 in order to bring them into line with workshop practice.

The authors stated (page 1095) that failure of high-speed steel tools was brought about by the fusing of the nose due to heat generated as the result of friction, the friction being due to: (1) the rubbing of the chip on the upper face of the tool; and (2) to the cutting action of the tool as it traversed the work in a line parallel to the axis. This statement was not quite correct. Except for very fine cuts, the amount of work done in pushing the shaving across the tool-face did not amount to 15 per cent. of the whole work done at the tool-point. When operating on steel at a high speed, it would be observed that the shaving pressed hard on the upper surface of the tool at some distance back from the cutting-edge, with the result that the shaving was twisted from the stock. This twisting action caused the shaving to tear in advance of the tool-point, and to produce an intense heat in the shaving itself, which heat was conducted to that part of the tool most closely in contact with it. The point of the tool simply cleaned up the bar, and a pile of small cuttings, which had been imprisoned in the rent between the shaving and the bar, was firmly deposited on it. This small heap adhered to the edge of the tool at the base, but the top was being continually removed and replenished by fresh stock from the bar, which action assisted in carrying off the heat from the tool-point. The greatest temperature and pressure were where the heel of the shaving bore on the tool, and these, together with the speed at

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which the shaving slid across the face, gradually wore a groove at that part, which deepened and widened until it extended to the cutting edge, whereupon the lip broke down and the tool failed. Thus failure was caused at high speeds, not by the tool getting hot at the point, but at some distance back from the cutting edge, thus facilitating the grooving action which led to the destruction of the edge. The tool was found to be cooler at the cutting edge than at the part where the groove was forming. Heat flowed, of course, by conduction from the hot region behind the point to the cutting edge; but the edge was kept cool by a continuous supply of fresh cold bar.

The law of grooving depended upon: (1) the normal pressure on the tool due to the twisting of the shaving; (2) the speed at which the shaving slid over the tool; and (3) upon the temperature of the surface of the tool in contact with the heel of the shaving, that is, where the tool was hottest. Except for very fine cuts, the normal pressure was practically independent of the area of cut, but varied with the cutting angle of the tool. The ratio of the speed of sliding to the cutting speed was the same as the ratio of the shaving length was to the length cut, and this had been shown to closely approximate $\frac{0{\cdot}45}{\sin a}$, where a is the cutting angle of the tool.

Concerning the relation between the cutting speed and cut when operating with high-speed steel-tools, the general expression advanced by Mr. F. W. Taylor was given on the next page, and in this V = cutting speeds in feet per minute, D = depth of cut, F = feed in inches per revolution of the work, and r the nose-radius of the tool. As r varied with each tool section the values of r given by Mr. Taylor have been substituted in the general expression, and a law obtained for each tool as shown. From these it would be observed that the authors' law approximately agreed with that given by Mr. F. W. Taylor for his smallest tool ($\frac{3}{32}$ inch nose-radius) and was very far out when compared with the laws given for tools having a larger nose-radius. In fact, the law for the $1\frac{1}{4}$-inch wide tool having a radius of $\frac{15}{32}$ inch was that given by Dr. Nicolson.

Mr. F. W. Taylor's Expression: High-Speed Steel on Steel.

$$V = \frac{C\left\{1 - \frac{8}{7(32r)^2}\right\}}{F^{\left(\frac{2}{3} + \frac{2 \cdot 12}{5 + 32r}\right)} \times \left\{\frac{48}{32r} D\right\}^{\left(\frac{2}{15} + 0 \cdot 06\sqrt{32r}\right) + \frac{0 \cdot 8\,(32r)}{6(32r + 48D)}}}.$$

r	Cut = $\frac{1}{32}$ inch.	Cut = $\frac{1}{4}$ inch.
inch.		
$\frac{3}{32}$	$V = \frac{C}{F^{0 \cdot 665} D^{0 \cdot 360}}$	$V = \frac{C}{F^{0 \cdot 665} D^{0 \cdot 317}}$
$\frac{5}{32}$	$V = \frac{C}{F^{0 \cdot 612} D^{0 \cdot 394}}$	$V = \frac{C}{F^{0 \cdot 612} D^{0 \cdot 362}}$
$\frac{9}{32}$	$V = \frac{C}{F^{0 \cdot 551} D^{0 \cdot 443}}$	$V = \frac{C}{F^{0 \cdot 551} D^{0 \cdot 422}}$
$\frac{11}{32}$	$V = \frac{C}{F^{0 \cdot 532} D^{0 \cdot 462}}$	$V = \frac{C}{F^{0 \cdot 532} D^{0 \cdot 445}}$
$\frac{15}{32}$	$V = \frac{C}{F^{0 \cdot 506} D^{0 \cdot 496}}$	$V = \frac{C}{F^{0 \cdot 506} D^{0 \cdot 483}}$

The relation between the cutting speed with area of cut as a single variable, also the speed with depth of cut and feed per revolution as independent variables, had been already discussed before the members of this Institution, and as nothing further had been added to this matter, it could serve no useful purpose to return to it. The authors, however, claimed that their experiments and laws of cutting speed deduced from the same were in agreement with those of Mr. F. W. Taylor, and contrary to the experience and views of the late Dr. Nicolson. An examination of the above Table would show that the authors' claim was not justified. Dr. Nicolson contended that for all practical purposes, the cutting speed varied inversely as the area of cut to the *n*th power, where *n* varied with

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the material operated upon and quality of tool-steel used. For high-speed steel on mild steel Dr. Nicolson gave $n = \frac{1}{2}$, which figure gave values within 5 per cent. of the speeds attainable on ordinary workshop cuts with round-nosed tools.

With regard to the variation in output with area of tool (pages 1093, 1111–14, etc.), the tools used in these trials were of different

Fig. 55.

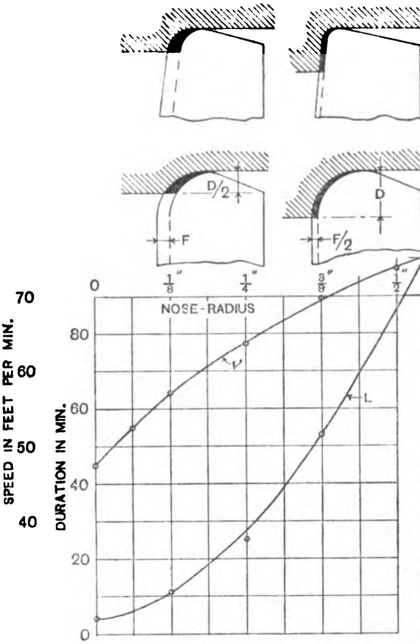
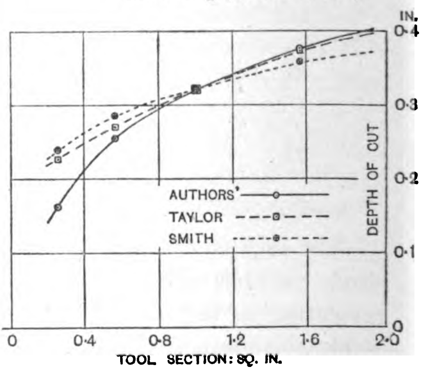


Fig. 56.

Comparison of Authors' curve showing Depth of Cut plotted against Tool Section with Taylor's and Smith's curves showing Depth of Cut plotted against Nose-Radius, Nose-Radius being taken to $\frac{1}{2}$ ($\sqrt{\text{Tool Section}}$).



cross-sectional area with cutting edges of similar geometrical form. The observations in these trials were shown diagrammatically on page 1113, and the increased output or permissible increase in the depth of cut with constant speed, feed and duration of run was attributed to the area of tool. In this the authors had been evidently misled, as, providing the curvature of the nose remained the same, the durability or performance of the tool was practically independent of the sectional area of the tool-steel. The increased performance could only be due to an increase in the nose-radius of the tool. In a Paper read before the Manchester Association of Engineers in 1911, he (Mr. Smith) stated that repeated tests with $\frac{5}{8}$ inch and $1\frac{1}{4}$ inch-square tools gave identical results when both tools had the same nose-radius, and, further, that the performance increased as the nose-radius increased. The same author showed that the relation between the durability of the tool and nose-radius could be expressed:—

$$L = C + r^{\frac{3}{2}},$$

where L is the life of the tool, C is a constant, and r the nose-radius in inches. This curve L was shown on Fig. 55. From the established relation of cutting speed to duration of run, this curve could be converted to give the variation of cutting speed with nose-radius for a constant duration. This relation was approximately given by $v = k_1 \, (r + k_2)^{0 \cdot 375} + k_3$, where k_1, k_2, and k_3 were constants. The curve corresponding to the latter expression was also shown on Fig. 55 and marked v. In the same way the curve for increase in speed with nose-radius could be manipulated to give the permissible increase in the depth of cut for constant durability speed, feed, etc.

Since with one exception the tools used by the authors were of square section, and their cutting edges were said to be geometrically similar, the nose-radius r might be assumed to vary as $\sqrt{\frac{a}{k}}$, k being a constant which was taken for convenience as 2. A comparison might now be made between the permissible increase in depth of cut as obtained by the speaker with change of nose-radius and that attributed by the authors to the cross-section. The comparison has been extended to include the results given by Mr. F. W. Taylor with tools of various nose-radii, and the whole were shown on Fig. 56. In making this comparison the value given by the authors for the one-inch tool was taken as a standard, and the constant in Taylor's and the speaker's expressions was modified to suit, and from this the values due to other tools obtained.

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With the exception of the authors' smallest tool the results generally agreed, and the whole consideration went to show that the permissible depth of cut for constant length of life, feed, speed, etc., increased with the nose-radius, and was independent of the tool section.

Mr. E. P. **Hetherington** said that Professor Ripper, before reading his Paper, expressed in a few words that he was rather taken aback at having to read it in Manchester. He (Mr. Hetherington) quite agreed with him; it ought to have been read in Sheffield and studied in Sheffield before it came to Manchester. His remarks, whilst not strictly in accordance with the Paper, must not be taken as against the authors, but in all his experience he had never heard a more sorrowful tale of the failure of high-speed tool-steel. It had been said—it was said when the Manchester tests were made—that there were no machines made that could stand up to the new tool-steel. It fell to the speaker's lot to make some of those experiments, or to be present when some of those experiments were made, and at that time he obtained some very valuable data.

He invited those steel-makers who were at the Technical School tests to go to the Works, and he would test their tool-steel. There were nine representative firms from all over the world who brought three tool-pieces of their own grinding and their own tempering, and there was not one of those tools stood longer than fifteen seconds. The maximum was fifteen seconds from the time it was put into the lathe, and that was commercial testing. The lathe destroyed the tools before they had made any length of cut. It was commercial cutting on 0·5 per cent. carbon-steel. It was declared by the steel-makers themselves that they could turn any steel at the speed of 200 to 250 feet. The tools were started at 98 feet, and destroyed in five seconds to fifteen seconds. He had not seen any tool-steel that could stand up to the tools that were manufactured by makers to-day. It had all been a case of failure of tool-steel from beginning to end. The makers would state at once that they could cut at over 200 feet. In fact, one gentleman from Austria started his sample tool at 400 feet, but the lathe destroyed it in two seconds.

Those were the points he wished to emphasize. It was not a question of tool-steel to-day, but it was a question for the steel-makers themselves to produce something that would stand. They had the machines that would do it, but they wanted the tool-steel to stand up to the work that was put before them on a commercial basis. All the small cuts mentioned in the Paper were nothing like what was wanted in Sheffield. There they had a Technical School under the charge of Professor Ripper, and were able to make their experiments, and on the Sheffield standard cuts of 1¼ inch deep and ½ inch thick. The question was: What was high speed? People would ask for a high-speed lathe. On inquiring the size of their engine, the answer would be that it was 10 h.p. "Well, I want 15, 20 or 30 h.p. to drive this machine." The speed and cut were given. Where was one to get a high-speed lathe? If one went into the pattern shop, a high-speed lathe could be got at once.

He thought the Council ought to create a standard of "high speed," and a definition of the term. His requirement was high speed and power—namely, ability to remove materials with deep heavy cuts—not simply high speed alone. As mentioned in his opening remarks, he thought this was a Paper, with all due deference to the authors and the Council, that should have been read in Sheffield to steel-makers, discussed, and remedied before reading it in Manchester.

Mr. **Daniel Adamson** said the Manchester experiments had been referred to so often that he thought it was due to the Committee, of which he was a member, to state publicly that the Manchester experiments were not competitive tests; they were rather an exhibition to show what could be done at that time. When these experiments were initiated nearly twelve years ago, there was very grave doubt expressed, even in Sheffield, about the capabilities of the new steels that were then being introduced. It had been said at this Meeting that the information published so far, including the

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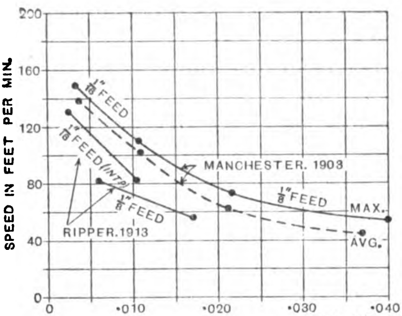
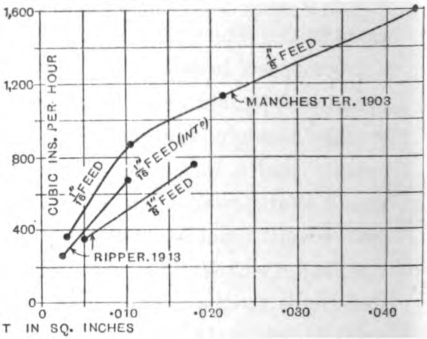
Manchester experiments, had been of an academic character. If the gentleman who said that no practical use could be made of them would read the discussion on their report, he would find that one prominent member of the Manchester Association, as soon as the report was issued, had charts prepared and put up in his workshops, and at the discussion (about a fortnight after the publication of the report) he was able to state that he had in that short time experienced very considerable improvement in the cuts adopted in his shops.

Most of the points that he (the speaker) might have referred to had been already brought before them by previous speakers, but he had prepared two charts, Figs. 57 and 58. The upper curves showed the range of the Manchester experiments on soft steel in 1903, being taken from Plates III and V of the Manchester Report. The two straight lines shown in the lower left-hand corner of each diagram covered the experiments on mild steel referred to in this Paper, being taken from Figs. 29 and 35 (pages 1099 and 1105). (The curves marked $\frac{1}{8}$-inch feed were taken direct, and the curves marked $\frac{1}{16}$-inch feed were approximated from the curves given in the Paper for $\frac{1}{12}$ and $\frac{1}{20}$-inch feed, so as to show something comparable with the $\frac{1}{16}$-inch feed results of the Manchester Report.) These diagrams

Fig. 57. Fig. 58.

Comparison of Experiments made in 1903 *and* 1913.





showed the relative importance of the Manchester experiments reported ten years ago and the results they had just heard.

On page 1134 of the Paper, however, there were some trials mentioned of cuts up to $\frac{3}{8}$-inch deep by 0·188-inch feed. Could not the results of these be included in the figures of the Paper?

Several speakers had expressed their great disappointment at the size and area of the cuts reported upon in the Paper. Six years ago the technical press reported that the Town Trustees of Sheffield had voted £2,500 for the equipment of a high-speed tool-testing plant in the Sheffield University. He had hoped that on the occasion of this first provincial Meeting of the Institution, with such an eminent author as Professor Ripper, they would have had a Paper that would be a considerable advance on what had been said before.

Referring to Fig. 57, taken from Fig. 29 of the Paper and Plate III of the Manchester Report, it would be noticed that two curves were shown of the Manchester trials, one being the maximum obtainable and the other the average of all the tools tried. The difference between these two was considerable, and he thought they should know whether the curves in the Paper were based upon the maximum results in each case or upon average results.

The implied criticism of Dr. Nicolson's views as to effect of area of cut on the cutting-speed, given on page 1101, was fully dealt with in his (Mr. Adamson's) reply to F. W. Taylor's Paper * before the American Society of Mechanical Engineers nearly seven years ago.

The illustrations of the tool on page 1071 of the Paper, showing the various angles, was insufficient, unless some mention was made of the position of the cutting edge in relation to the centres of the lathe. The shape of the tool had already been criticized by some of the speakers, and there was no doubt that a nose of greater radius on the tools would have considerably increased the duty obtained.†

It was very doubtful whether a run of 60 minutes, as advocated

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* Proceedings, A.S.M.E., vol. 28.

† *See* Mr. Adamson's remarks on Sir Frederick Donaldson's Paper, Proceedings, I.Mech.E., 1903, page 28.

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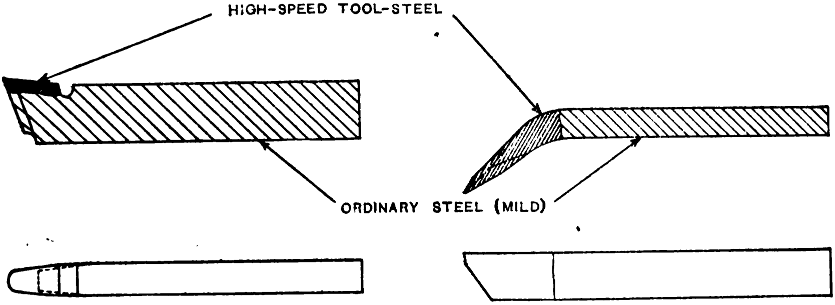
on page 1094, was really the most suitable for the purpose. In workshop practice it was seldom that cuts were required to run continuously for an hour, and even if so, it might be better to run, say, at 10 per cent. higher speed, and change the tools more frequently. At Manchester the cuttings of each trial were weighed so as to check the results obtained. Was this done at Sheffield, or were the figures based upon the assumed results of the intended cut?

On page 1107 a formula was given connecting the cutting-speeds with the tensile strength of the material being machined. In the Manchester report this formula was based upon the yield-stress of the material rather than the ultimate strength. Fig. 41 (page 1115) might be compared with Plate XI of the Manchester Report, which latter was based upon the carbon contents rather than upon the tensile strength of the bar.

Mr. G. H. Nelson said that a few years ago he made some experiments similar to the authors' in a fair-sized workshop in London, where they had been getting various outputs from different parts of the factory. They conceived the idea of making these tests to enable them to lay down some sort of routine to which a workman could work. Having made tools and having insisted on speeds of cuts suggested by the results of their tests, they were astonished at the general increase of output when the men were made to work in line with the results obtained from the experiments; but he might add that they had a difficulty in getting the workmen to carry out the instructions given to them. Some of them flatly refused, and said they had worked the old tools for years, and they saw no reason why they should change. Some of them had to be discharged before the firm were able to get results they desired. He would like to know if Professor Ripper would carry his experiments still further, in connection with various angles of tools, and lubrication, but this was a matter which had been already dealt with by previous speakers.

There was one other matter to which he wished to draw attention, namely, the cost. The cost of tools was a matter one hardly liked to bring forward in a Paper of such scientific interest, still to all manufacturers it was of great importance. Soon after these experiments (already mentioned) were made in London, in regard to output, he experimented with tools of a combination of ordinary steel and high-speed tool-steel. That is, the question of welding a small portion of tool-steel on to the ordinary steel, near to the point of cut, Fig. 59. He thought it would be of general interest and of commercial importance if Professor Ripper would carry his experiments in the direction of carrying out tests with tools of this description. In a large works, of course, where tools of large section were used, the cost of high-speed steel was of very considerable importance, and it was found that, at the works in question, where this method of welding tool-steel on to ordinary steel was tried, a considerable saving was effected in the tool bill at the works. Further, it enabled them to use up small pieces of high-speed tool-steel which previously had been sent to the scrap heap.

Fig. 59.—*Welded Cutting Tools.*



In conclusion, he must add that he considered the authors' experiments, and results obtained therefrom, as being most valuable. As a previous speaker had remarked, they must rely on the Universities and Technical Schools for conducting experiments on a scientific basis, as had been carried out by the authors. A manufacturing firm could neither spare the time nor money for such thorough investigations.

Mr. E. MILLINGTON (Midland Railway, Derby) said that it would be gathered from what had been said by the various speakers, that there was still a great difference of opinion on the question before them. They had heard much about speeds and feeds, and the question of the correct cutting angle to use. As regards the latter point, it would appear that there was a very great difference of opinion, more so than the correct feed and speed. In his opinion, all these factors depended to a very great extent on local conditions, such as the quality of the material operated upon, and many other incidental factors, and any attempt to apply universally any set rule must in many cases necessarily fail.

There was another factor which seemed to have escaped attention, which he thought had a very important bearing on the cutting power of tool-steel. During the discussion not a word had been said on the question of hardening or composition. From numerous researches carried out during the last ten years by various eminent scientists on this question, it had been shown that the heat treatment was the factor on the question of hardness, and hence the cutting power. During the past year it had fallen to his lot to test high-speed tools for turning hard railway tyres. From about twenty tests very widely differing results had been obtained, and in very few cases had the results reached a figure usually obtained, and which was used as a basis. He could not help thinking that in some cases at least the method of hardening had been chiefly at fault, in others perhaps composition also. Therefore, under such circumstances, always bearing in mind that the same material was operated upon, it would be very difficult if not impossible to apply the results obtained by Professor Ripper without modification to suit each class of tool-steel.

Again, the results of a large number of careful tests appeared to show that one method of hardening would give results on one class of material, which it might fail to produce on another class. Taking a case the speaker had in hand at the present time, using one brand of high-speed steel as an example, it had been found that certain heat treatment would give excellent results on wrought-iron which were not produced on cast-iron or mild steel. A modification of the heat treatment of the same tool had produced corresponding varying results on the above-mentioned material. This perhaps explained why certain fancy exhibition performances were not always repeated in the workshop. It would therefore be seen that to obtain the test that any certain brand of high-speed steel would produce, it was necessary to ring the changes on the various methods of hardening. He had mentioned the point of hardening high-speed steel, because he considered it had a very important bearing on the performance of the tool, and then on the question before them this evening. It could hardly be claimed that a Paper was complete without taking this question into serious consideration, and since it was not mentioned in the Paper, he assumed that this factor was a constant.

In equation No. 4 (page 1090) tensile strength was one of the factors, and he would like to ask if elongation had no influence on the point, or was ductility regarded as a constant figure in relation to the tensile strength. He ventured to suggest that tons per square inch was not the only factor entering into the cutting power of a tool, but that toughness also affected the question. Some time ago he made some tests with a view to ascertaining how the elongation of a metal affected the hardness. He found that it did not necessarily follow that, the tensile strength being constant, the lower elongation always gave a higher hardness figure. On the other hand, it was frequently found that the higher elongation gave an equal and in some cases a higher figure of hardness. Therefore it seemed to him that the question of elongation must enter the question, and that equation No. 4 would be affected accordingly. In mentioning these several points he did not wish it to be thought that he depreciated the value of the Paper. On the other hand, he congratulated the authors on the results obtained, and trusted that they would pursue the matter still further. They all knew the limitation of the University, and that it was not an institution meeting with the conditions and demands of a workshop; and that fact must be allowed for. What was wanted was something which could be substantially reproduced in every-day practice with the

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necessary modifications. It was doubtful if a formula could be found which would apply universally, but rather would it appear that general principles must first be obtained. Using these as a basis, and introducing the various incidental factors in their application, appeared to his mind the only way to apply successfully the science of cutting tools. From the curves and formulæ set forth in the Paper, the authors could claim very substantially to have found a basis, and for this they were to be congratulated.

The **President** said that it was about time that this Meeting should be adjourned until to-morrow, when he hoped that the discussion would be resumed, and that many of the audience would be in London to continue it. In the meantime, though they did not expect Professor Ripper to go through the whole of the reply this evening, he would perhaps say a few words.

Professor **Ripper** said he was sure they would sympathize with him when he stated that he did not propose to-night to reply to the criticisms on the Paper, but he wished to express his thanks to the Meeting for the very kind and very fair way in which the Paper had been discussed. (*See* pages 1193 and 1199.)

Discussion in London on Friday, 21*st November* 1913.

The **President** was sure the members would desire that the usual vote of thanks should be accorded to the authors for their Paper, which was full of the keenest interest. There were reasons why the vote of thanks should be something more than usual, because the authors had been good enough to deliver the Paper twice—once on the previous evening in Manchester, to a crowded Meeting of nearly 300; after which they travelled to London to read the Paper again on the present occasion. He therefore asked the members to accord the authors an extra hearty vote of thanks.

The resolution was carried with acclamation.

The President, having invited the members present to discuss the Paper, and there being no immediate response, said that as there was an absence of alacrity on the part of the members on the other side of the table in rising to discuss the Paper, he had better start the discussion himself. The subject with which the Paper dealt was one in which he had been very much interested, particularly in years gone by when high-speed steel was becoming a matter of moment to everybody who had to deal with workshop practice. Professor Ripper had stated quite frankly that he regarded the investigation that had been carried out as a step in the acquisition of knowledge, and that the results were not to be regarded in any sense as finality. That, of course, must be so because from the lines on which the authors had acted in carrying out the experiments they had deliberately—and he thought quite properly—removed all variables that they possibly could; that is, they had taken one set of angles for a variety of speeds working on a variety of materials.

Some years ago a series of experiments was carried out at Woolwich Arsenal with carbon-steel tools, and subsequently with high-speed tools, but those experiments were primarily aimed at the effect of the angles of cutting tools rather than the amount of material removed, although that was a factor in the experiments. He did not propose to deal with those experiments, because he submitted their results * to the Institution in 1903. The point he wished to make in connection with it was, that he entirely agreed with the authors that for roughing cuts and heavy cuts slow speed gave the largest output; but in dealing with finishing cuts, where less metal had to be removed, it would not follow that the same conclusion did not necessarily hold. That would perhaps account for apparent discrepancies between the authors and some other investigators. With the use of high-speed tools, heavy cuts were generally more desired than light cuts, because it was very much the practice at present to avoid the finishing cut and to finish by grinding. He therefore thought it was quite right that the investigations should deal with the bulk of the heavy work, and he

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* Proceedings, I.Mech.E., 1903, page 5.

(The President.)

thought the authors had taken the members some little way on the road in that connection.

The authors had introduced one or two things which were, he thought, a distinct addition to the advantages engineers were enjoying at the present time. But he did not quite agree with the statement in the first paragraph that the subject was one about which there was very little information. He would not disagree as to the information not being available for use, but he believed that much information was in existence, unpublished and therefore lacking. The members would appreciate the difference. He expected there were many present that evening who had a good deal of information on the subject of cutting tools, but it was locked away in their pigeon-holes or somewhere else; it did not come out. The present was an instance where the subject that Mr. Roberts dealt with so ably at the Cambridge Meeting—the collation of research—might tend to assist matters very much indeed.

There was another thing which he thought was greatly wanted. Professor Ripper and his co-author had adopted names for the angles of the various parts of the tool. He was afraid that he personally adopted the same names more or less applied to different parts of the tool, so that some sort of standardization of nomenclature was desirable. If that standardization was brought about, when people talked of "top-rake" everybody would know what was meant by that expression.

He next desired to draw attention to the considerable differences which he found in the results of the experiments conducted at Woolwich as compared with the results arrived at by the authors. If he properly understood what the authors meant by top rake, he was able to put his own figures against theirs. The experiments made at Woolwich in 1901, which were communicated to the Institution in 1903, were made upon different qualities of materials—he was speaking now of carbon-steel tools. The material cut varied considerably, and consisted of mild steel, oil-hardened steel, and a very hard steel alloy containing a large percentage of chromium and other things unpleasant to cut. He referred those of the members who were sufficiently interested in the subject to the Paper he had mentioned; taking only the top rake as compared with the authors' angles, it would be seen that for cutting mild steel the best top-rake angle was found in the Woolwich experiments to be from 22° to 35°. Personally he did not regard the top-rake as the angle of greatest importance, but gave it more to the front cutting angle. For the medium steel, that is, the oil-hardened steel, 19° to 33° were found to be the best angles, and for the very hard steel 4° to 22°. That was a very considerable variation, but he was not prepared at the present moment to argue why there should be such a large variation. Against those three sets of figures, the members had the 11° given by the authors. He wished to base upon that the suggestion that Professor Ripper and his colleague should extend their investigations.

Having experimented with one angle only, it would be very useful if the authors could see whether they could correct the figures and bring the margins for the "best possible" nearer together than was done in the experiments to which he had referred. If a further reference was made to the Paper which he had mentioned, and to that part in which it would be found he was dealing with high-speed steel, he would take only one angle, the top-rake again. Whereas, according to the authors, the best angle for cutting very hard steel was still 11°, in the Woolwich experiments it was found to be 5°, and for cutting the oil-hardened steel 12°. That was rather a curious thing, for the steel castings, which were really mild steel, were dropped back to 6°, that is, the very hard material was cut with an angle of 5°, and the soft steel with an angle of 6°. When the side cutting was dealt with, however, the difference was very great, that is, in the front cutting, which, as he said, he regarded as the most important, they had 79° against the authors' 74°. The latter figure of 74° just agreed with the oil-hardened material which they were working upon, where they found 74° to be the best angle.

He thought that perhaps a comprehensive Table of comparison with his results and those of the authors might be useful, and he had compiled the Table (page 1178) for the purpose.

He did not wish to labour the point, for, as he had said before,

(The President.)

Purpose: Ordinary carbon-steel tool.	Top Rake.	Side Rake.	Front cutting.	Side cutting.	Front clearance.	Side clearance.	Horizontal.	Remarks.
For cutting mild steel . . .	22°–35°	22°–37°	52°–60°	50°–60°	3°–8°	3°–8°	33°–43°	Donaldson, Proc. I.M.E. Jan. 1903, page 18 amplified.
For cutting medium steel . . .	19°–33°	17°–27°	54°–63°	60°–65°	3°–8°	3°–8°	33°–43°	
For cutting hard steel . . .	4°–22°	12°–27°	65°–78°	60°–70°	3°–8°	3°–8°	33°–43°	
Ripper's standard tool . . .	11°	23°	74°	62°	5°	5°	65°	Ripper's Paper, pages 1071–2.

if the Members were sufficiently interested to compare his results with the authors', he thought some useful information might be obtained. Personally, he would be delighted, if the authors would be good enough to carry their work further than they had so far done, and to check his angles.

With the endeavour to bring a practical issue to bear on the Paper, he desired to refer to a point towards the end of it which the authors had not mentioned, and to suggest a means by which practical effect could be given to the investigations which had been carried out. He supposed that if there were a hundred makers of high-speed tool-steel at work at the present time, there would be something like a hundred different classes of high-speed steel, so-called, made at varying prices. He did not know that those varying prices were supposed to meet all demands, but there was no doubt about it that most of the makers desired special treatment of the tools according to the particular steel they made. If a user intended to buy high-speed steel on a fairly large scale, he ought to have some idea that he was getting the best for his purpose. It did not necessarily follow that steel from firm *A* would be the best for the purpose *Z*, whereas it might be the best for purpose *M*. It did not at all follow that the most expensive steel to be obtained from firm *B* met the user's requirements. It might be absolutely the best for some particular purpose, but it might not suit a particular user. The user therefore had to lay down what his own requirements were, and having laid them down he had to make the steel-maker understand the requirements and what tests he proposed to put the material to, so that he might fulfil his requirements at a price which suited both. Taking the case of Woolwich, they had three main uses for high-speed steel, namely, mild steel, oil-hardened steel, and very hard steel alloys of various kinds.

Ever since the experiments referred to in the Paper he had mentioned, they had laid down at Woolwich a certain line of procedure. All makers were invited to supply samples of their steel for trial purposes, and those samples were tried on a regular and similar basis, that is, first of all, minimum speeds, feeds, and cuts

(The President.)

were adopted for each of the classes of material dealt with. Then the tools were treated in accordance with the requirements laid down for the treatment by the steel-maker; then they proceeded to try them on material at the speeds laid down, that is, on the very hardest material for a period of five minutes, for the medium hard material ten minutes, and for the soft material fifteen minutes. That had the effect of weeding out a good many samples. Those that remained were then speeded up by about 25 per cent., and were continued at work for half an hour or an hour, so that eventually the final test, which was called the removal test, was arrived at, which was really the same thing as the authors had dealt with in the Paper. The outcome of such tests had enabled the authorities to decide which kind of high-speed steel best met their requirements from the points of view of efficiency and economy in working, for data was obtained by them to show the weight of material removed and also the comparative tool cost.

Mr. **Loughnan Pendred** said that he attended the Meeting with the intention of speaking on a particular subject, but in his opening words that evening, which did not then appear in the Paper, Professor Ripper had rather forestalled him by referring to that particular subject himself. But as it was possible that a number of the members present were not acquainted with the experiments to which he referred, those of Mr. E. G. Herbert, it might be worth while if he gave a very brief outline of the methods that Mr. Herbert had adopted and the extraordinary results he had obtained. Mr. Herbert's tests were made, not in a lathe but in a machine more like a drilling machine. He used, instead of the bar which was usually turned, a tube, which was rotated as in a drill press. The principle of the machine was shown in the following diagram, Fig. 60. The tube was $\frac{3}{4}$ inch in diameter by $\frac{5}{8}$ inch bore. It was pressed down by a heavy weight against a dead stop. The tool itself was shown in the diagram, and it would be seen that it bore against the lower edge of the tube. As the tube was rotated, metal was removed steadily all round the rim, and the weight brought the tube down again so that more was cut off. The tool was carried on the end of a lever, which was so adjusted that a given pressure could be imparted to the edge of the tool in order to get the amount of cut that was desired. The standard bluntness which had to be obtained, just as the authors had to obtain it, was got by the deflection of the lever. When the lever deflected a certain amount by the wearing away of the edge of the tool, it made an electric contact showing that the standard degree of bluntness had been obtained. The endurance that Mr. Herbert sought was not a time endurance but an endurance by the amount of material removed. Fig. 61 was taken from the first of two Papers read before the Iron and Steel Institute (1910, No. I, Fig. 24, p. 238), which did not receive the attention it deserved, because it was not read before the Institution of Mechanical Engineers, which was the proper body to discuss machine-shop questions.

Fig. 60.

Principle of the Machine used in Mr. Herbert's Tests.

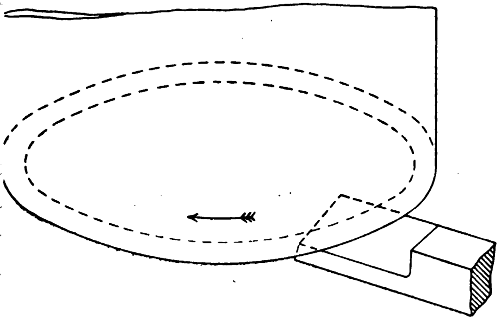
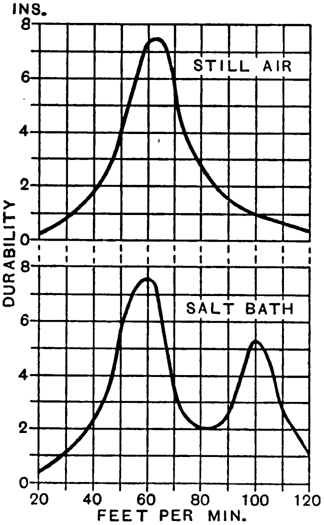


Fig. 61.

Tungsten-Vanadium Steel Hardened at Low Temperature.



The durability, measured in inches of metal removed, was shown by the vertical scale, and the speed in feet per minute by

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the horizontal scale. At a very low number of revolutions per minute Mr. Herbert found that he was able to remove only a very few inches of material; if he increased the number of feet per minute he removed a great deal more material.

With certain steels a very remarkable fact was shown (*see* the lower diagram). At 20 feet per minute very little metal was removed; at 60 feet per minute a great deal was removed; at 80 feet per minute the endurance went back to a very little, but if the speed were increased further the amount of metal removed went up to another point where the endurance had increased from the minimum that was reached before. He intended to have asked the authors if they had taken those experiments into consideration, and if they could carry their tests further to find out if Mr. Herbert was correct; but apparently, from what Professor Ripper had said that evening, it was those very experiments that had inspired the present Paper.

Mr. G. H. **Roberts** said that having had some experience in carrying out trials of steels to be used as lathe turning tools and for various other purposes, including some of those to which the President had just referred in his remarks, and also having had the advantage some little time ago of going over the authors' equipment and some of the preliminary experiments, which he supposed led up to the trials now under discussion, he wished to express his appreciation of the amount of work involved in the Paper, which as he knew from his own experience must have been very considerable. He therefore desired to say, in the first place, that he hoped it would be found that any remarks he had to make would be principally in the nature of constructive rather than destructive criticism.

The first point, quite a small one, to which he wished to refer was on page 1070, where the authors said: "The characteristic composition of carbon tool-steel is approximately as follows," the composition then being given. To any one familiar with the manufacture or use of carbon tool-steel, the intention and meaning would be perfectly obvious, but to others such a generalization might possibly lead to misconception, as the carbon content in ordinary tool-steels varied, according to the purpose for which the steel was intended, from 0·8 per cent. to 1·4 per cent. He therefore suggested the statement would be more correct if the authors added after "carbon tool-steel" the words "as used for lathe or similar tools."

On page 1074 the authors referred to the difficulty of finding a standard for the breaking-down point of the tools. That difficulty was well known to every one who carried out such trials, especially with ordinary carbon-steels. He thought the authors had met that difficulty rather neatly, although somewhat arbitrarily, but he would like to ask whether they had considered the advisability or the possibility of laying down a standard of bluntness as determined by the reading of the ammeter, that is, by observation of the amount of power taken by the lathe during the progress of the test. In trials of this kind the horse-power or the amperes taken usually went up very rapidly when the tool began to break down, and in many cases he had found that such increase indicated fairly definitely the breaking-down point of the tool. Perhaps the authors had made observations on that point and would, when replying to the discussion, say whether they considered that an observed increase of, say, 25 per cent. in the amperage could be used to define the breaking-down point.

At the bottom of page 1074 the authors referred to the curious phenomenon of the building up of a false nose, and those who had carried out steel trials of this kind had no doubt noticed, as he had himself on many occasions, this false nose. He had actually seen it built up to a height of $\frac{3}{16}$ inch, and although the tool itself had previously shown every sign of breaking down, with an increase in the power absorbed, when once the false nose was formed it went on cutting again, the power going down to approximately what it was before, and they then had the very curious phenomenon of a steel cutting itself, and almost as efficiently as the crucible-steel tool, although the stock being worked upon might be quite a mild steel.

Half-way down page 1080 the statement was made: "In all

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cases the work has been run dry, that is, without lubrication at the cutting edge of the tool." If he might say so, he thought that was unfortunate. No doubt the authors had good reasons for determining on that method of operation, but he thought they would agree with him that it did not represent workshop conditions, and therefore made it difficult, if not impossible, to apply the results to actual workshop practice, whilst in addition it did not show the best results of which the tools were capable. Probably the reply to that criticism would be, that if lubrication were used it would have introduced another variable. That might be true to some extent if the ordinary drip-can method were used, but if copious lubrication had been employed that difficulty would not have occurred to any considerable extent. Indeed, it was quite conceivable that if properly arranged, copious lubrication would tend to make the cutting conditions more constant and to eliminate some of the varying factors (due to heat radiation and conduction) which were no doubt present under the conditions described.

At the bottom of page 1080 reference was made to four figures, Figs. 12, 13, 14 and 15, containing representative curves for each of the four test-bars, and the respective areas of cut were given with $\frac{1}{24}$-inch feed. He supposed the authors had some good reason for choosing $\frac{1}{24}$-inch feed, but it made it difficult, if not impossible, to compare the results given in those same curves with those obtained in curves 4 to 11 where the feed was $\frac{1}{36}$-inch.

Near the bottom of page 1083 the authors gave the equation $M = \frac{\text{constant}}{S^5}$. He found on taking one of the fairest curves, namely, Fig. 13, and plotting the figures there given as logarithmic curves, that the equation came out almost exactly $M = \frac{\text{constant}}{S^6}$. That was only a trifling point of detail, but there might be some explanation of the difference.

The most serious point he wished to raise in connection with the Paper was that the authors introduced about half-way down on page 1085, the fundamental conception of the "associated" cutting-speed, which was used constantly throughout the remainder of the

Paper. That "associated" cutting-speed involved two, or perhaps three, variables which were introduced and subsequently used as one. Thereby it appeared to him the authors had violated one of the fundamental principles of scientific research, in that an investigator should introduce only one variable at a time. Probably the authors would not plead guilty to that charge; but, at any rate, he found in reading the Paper through that it made the correct interpretation of the subsequent results very difficult.

Professor **Ripper** asked Mr. Roberts if he would explain exactly what he meant by the three variables.

Mr. **Roberts** said that the authors took a given area of cut, which was the product of the feed and the depth of cut. From that they deduced what they called the "associated" cutting-speed, which produced unit bluntness after a 60 minutes' run, and so obtained one compound variable, if he might so term it. Then, later on, they gave figures and curves where that "associated" cutting-speed was used as one quantity and connected with other things, as, for example, in formulæ 7 and 8.

Near the top of page 1086 the authors said: "It also shows that large output is by no means associated with high cutting-speed, but that as the cutting-speed is reduced (with, of course, a suitable increase in the area of cut), the output is increased; in other words, a heavy cut is better than a high-cutting speed." He suggested that it would form an interesting corollary to that statement, and be of utility from a purely workshop point of view, if the authors could give the relationship between the cutting-speed at a given fixed area of cut and the life of the tool measured by the total volume of the material removed.

A few lines from the bottom of page 1086 the statement was made: "It will be seen that the greater the area of cut, accompanied by its appropriate or 'associated' cutting-speed, the greater the volume of metal removed. In other words, a low cutting-speed and heavy-cut combination is preferable to a high cutting-speed and light-cut combination from the point of view of output." It

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was rather interesting to notice that that formal statement was a confirmation of an old workshop adage which was impressed upon the speaker when working at the lathe, namely, "cut deep and feed fine." That was, of course, a workshop way of putting it, but it came to the same thing and was substantially true even with the modern high-speed steels.

At the top of page 1090 the authors referred to the most suitable method of determining the hardness of the material, and finally arrived at the conclusion that this would be given by a tensile or crushing test. He would like to ask whether they had considered, and if so why they had not used, the Brinell test or the scleroscope either in lieu of the tensile test or in addition thereto, because these gave useful and comparative information which was more readily obtained than by the ordinary tensile test.

Near the top of page 1093 the statement was made: "The tools were made of a high grade of high-speed steel, shaped entirely by grinding in a universal tool grinder—thus dispensing with the necessity of forging—and then hardened according to the directions of the maker. This size and shape of tool were adopted so that the tests would be comparable with those made on the carbon-steel tools." That was a perfectly good and correct procedure, having regard to the ultimate purpose of the present investigation, but he did not think the authors would wish it to be understood that the same angles were always the best for both classes of steel. For instance, it was well known to those who worked high-speed tools that in many cases they would with advantage stand having blunter cutting angles than the ordinary carbon-steel tools. Perhaps the authors had obtained information from their experiments which might throw some light on that point, to which the President had also referred.

Near the top of page 1095 the statement was made: "When the tool is worked under conditions which are not excessively severe, the heat generated at the nose of the tool is conducted away as fast as it is generated, and thus the nose is not subjected to overheating; but if the conditions of speed of cutting and of area of cut are such as to generate heating of the nose faster than the tool can conduct it away, fusing and breakdown at the nose takes place." With regard to this it was a curious thing, in which those who had had much experience of high-speed steel would, no doubt, bear him out, that many of these steels had what might be called a critical life-temperature point, that is, if they started cutting with a high-speed steel under certain severe conditions of cut the tool might break down at once whilst it was cold, but if it could be got to stand up to the work for a few minutes until it was warmed by the heat generated, then it would probably pass the critical point and go on cutting satisfactorily. He believed Mr. E. G. Herbert had drawn attention to that point in his Paper read before the Iron and Steel Institute to which Mr. Pendred had referred.

Professor **Robert H. Smith** said he had read the Paper with very great interest, and thought hearty thanks were due from the profession to the authors for the large amount of work they had undertaken on such an important subject. He admired the Paper particularly, not only because of the very large amount of accurate and careful work which it represented, but also because the aims of the experiments throughout were of commercial workshop utility. He did not say that the investigation aimed at all the objects of commercial utility, but all the objects that were aimed at in the Paper were of commercial utility. He had no objection whatever to the standard units used throughout the Paper, provided always it was very distinctly understood that they were entirely conventional units and not natural units. As had been suggested by Professor Ripper, it might very well be found later on that it was desirable to change those units.

With regard to the remarks that had just been made as to the term "associated" cutting-speed, certainly that standard as used in the Paper was a compound standard. It depended upon various factors that were put together to get at that standard, and those factors might be varied independently; but for the object in view it was necessary to use some standard of that sort, and he did not think reasonable objection could be made to it because it was compounded of variable factors, provided that the composition of the

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factors gave, as it did in the Paper, one definite value to serve as unit.

A definition was given (page 1073) of what was called blunting, and it was measured by a quantity that was called W in Fig. 2. He wished to ask how that dimension W had been measured with microscopic accuracy. One could see quite well the little blackened area on the lower part of Fig. 2, and the outside edge of that blackened area was quite definite, but the inside edge appeared to him rather difficult to locate accurately. Did it depend upon the actual depression of the material at that edge observed in some way or other, or by the actual observed wear of the material, or by the limitation of an observed rounding of the point, or by a polishing of the surface? He would like to know exactly how that edge was determined. Another way of measuring the blunting was the following: The tool-point was originally more or less sharp, and when it was blunt it was more or less rounded. With a micrometer-screw or other form of gauge it would be quite possible to measure the distance *d*, Fig. 62 (page 1192), the wear from the original sharp point to the nearest point of the round.

Exceedingly interesting results were given on pages 1084 and 1101, Figs. 16, 17, and 31, co-ordinating the cutting-speeds with the duration in minutes through which the tool stood up to standard bluntness. In Fig. 16 the time in minutes was said to be a constant divided by the fifth power of the cutting-speed. He always looked with scepticism upon those exponential formulæ. There was a craze for logarithmic plotting of results, independently of whether such plotting and such exponential formulæ could possibly rationally correspond with the physical facts. He did not think they always did, and he thought the form of the equation given showed that it could not be a rational one; in fact, Professor Ripper himself pointed out that it only applied to a certain portion of the length of the curve and not to its extremes. The same remark applied to Fig. 17, which co-ordinated the sectional area of the chip with the cutting-speed; and also to Fig. 31 (page 1101), which was for high-speed steel where the speed was co-ordinated with the feed and the depth of cut separately. All the curves that were seen in those diagrams, and a great many other similar diagrams in the Paper, were really practically hyperbolic, and it was not difficult at all to find out the constants for the hyperbolas that represented them. It involved the shifting of the geometrical axes of the hyperbola from those denoting the zeroes of the physical quantities co-ordinated, and two of the three constants required to be found were the respective shiftings of the two axes. If a formula was obtained in that form, it at once showed the minimum speed to which the authors referred frequently in the Paper—the low speed at which one could go on cutting practically as long as one liked without damaging the tool. He desired to give the followin examples of this formula:—

For Fig. 16.

Bar W: $$S = \frac{255}{M + 14 \cdot 4} + 12 \cdot 3.$$

Here 12·3 was the minimum speed.

Bar X: $$S = \frac{129}{M + 9 \cdot 1} + 10 \cdot 8.$$

Here 10·8 was the minimum speed.

Bar Y: $$S = \frac{444}{M + 33 \cdot 3} + 6 \cdot 7.$$

Bar Z: $$S = \frac{150}{M + 20} + 3 \cdot 5.$$

M was the number of minutes. The minimum speeds went down in a very regular progression. In those cases the minimum factors did not follow any law which he had discovered as dependent upon the hardness of the steel cut. But such a law might possibly be found by further investigation, for which he had neither the time to carry out nor the data. The formulæ for Fig. 17 (page 1084) and Fig. 31 (page 1101) were as follows:—

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For Fig. 17.

Bar W: $$S = \frac{0{\cdot}0433}{A + 0{\cdot}00086} + 3{\cdot}1.$$

Bar X: $$S = \frac{0{\cdot}0357}{A + 0{\cdot}00114} + 2{\cdot}2.$$

Bar Y: $$S = \frac{0{\cdot}030}{A + 0{\cdot}0010} + 1{\cdot}55.$$

Bar Z: $$S = \frac{0{\cdot}0147}{A + 0{\cdot}00072} + 0{\cdot}43.$$

Here $$S = \frac{C}{A + A_0} + S_0.$$

$$\therefore \quad SA = C + AS_0 - \frac{CA_0}{A + A_0}.$$

$$= C - SA_0 + \frac{CS_0}{S - S_0}.$$

$$\therefore \quad \frac{d(SA)}{dA} = S_0 + \frac{CA_0}{(A + A_0)^2} > 0 \text{ always,}$$

and $$\frac{d(SA)}{dS} = -A_0 - \frac{CS_0}{(S - S_0)^2} < 0 \text{ always.}$$

For Fig. 31.

$D = \frac{1}{16}''$: $$S = \frac{4{\cdot}37}{F - 0{\cdot}005} + 42{\cdot}6.$$

$D = \frac{3}{32}''$: $$S = \frac{4{\cdot}49}{F - 0{\cdot}002} + 33{\cdot}5.$$

$D = \frac{1}{8}''$: $$S = \frac{4{\cdot}55}{F + 0{\cdot}0025} + 26{\cdot}3.$$

Here there appeared to be a fairly regular progression in each of the three constants.

Those formulæ appeared to him to be more rational, and also very much easier of arithmetical application than those given; they were capable of representing each curve truly right through its whole length. The formula "MS^5 = constant" involved only one constant, so that it could be made to apply quite accurately to only one point of the curve. The hyperbolic formula involved three constants, so that it might be made to pass quite accurately through three points of the curve, and if one understood the general nature of the curve and got it to correspond exactly with three points in the curve, one surely could not be far wrong.

He thought that Fig. 20 (page 1088), co-ordinating speed and tensile strength, was of special interest and importance, as were also the Figs. on pages 1098 and 1100, as they showed very simple relations dependent upon the hardness of the material cut. Again, Fig. 36 (page 1106) appeared to him to be of very great use for the same reason. Figs. 41 and 42 (pages 1115–6), which dealt with the horse-power, were very curious indeed, and, taking for granted that they actually represented the physical fact, they were of extreme workshop utility. In the last part of the Paper the new method of speed increment test was described. He only wished to say, in passing, that it appeared to him to be an extremely good form of test, easily applied, so as to give definite and exact results, and it was not subject to any serious objections that he could see.

Passing to some general remarks, what he had to complain of in the Paper was that it did not cover the whole field; it left out a great deal that was of extreme importance. For instance, as had been already mentioned, it dealt only with dry cutting. Dry cutting was absolutely unreasonable in most tooling, especially with modern high-speed tools. It was not only a question of lubrication, as the previous speaker had stated, but also of cooling. The heavy cuts taken at high speeds were invariably taken with quite a deluge of not lubricating material, or, at any rate, very slightly lubricating material, but of cooling material. Another general remark was that the whole Paper referred to efficiency of various kinds with regard to the volumetric or weight output. An investigation of that kind was of very great use, but the volumetric output was not always the commercially useful result. It was only so in roughing cuts or in tearing down big ingots. On finishing cuts and polishing cuts quite a different aim had to be kept in view. There it was necessary to aim rather at a surface output in the minimum possible time.

In the next place, with regard to the depth of cut, Dr. Nicolson said that it did not much matter how the cross-sectional area of the

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shaving was made up, whether of large feed or of large depth. That he (Prof. Smith) had never agreed with; his own experiments showed him quite the contrary. The authors said that it was approximately true with regard to carbon-steel tools, but they found a difference with high-speed tools. His own experiments showed a very decided difference when experimenting with carbon-steel tools as well. The variation did not depend exactly upon the depth of cut. What was really of importance was the proportion of the length of cutting-edge to the thickness of the shaving, namely the ratio of the dimensions marked L and T in the sketch, Figs. 63 and 64. The length L of the cutting-edge was not the same as the depth of cut, and it was quite necessary to make a distinction between the two. He suspected that Professor Ripper had gone wrong in his assertion that in carbon-tool steels the ratio of those two things did not make very much difference, because he had used throughout very small cuts. He had really been experimenting upon not much more than point cutting. The biggest depth of cut the authors used was something like $\frac{1}{8}$-inch. Under those conditions the heat flowed away readily from the point through the area of metal over a field of 90° and sometimes more than 90°. When cutting with a long cutting-edge the heat flowed away only at right angles to the long cutting-edge, and that made a very great difference. It was also necessary to consider the bending moment of the force exerted by the tool that bent and broke the shaving. This diminished very quickly with the thickness T. He thought that the

Fig. 62.

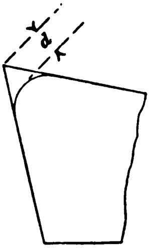


Fig. 63.

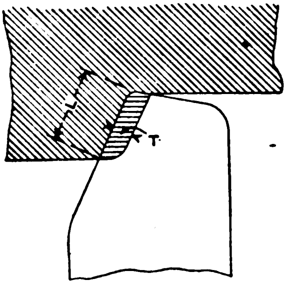
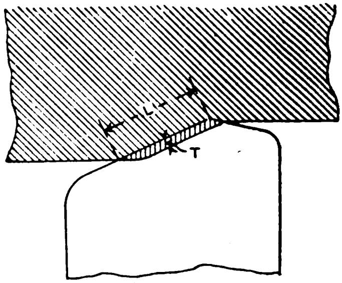


Fig. 64.



difference between the depth of and the length of the cutting-edge was very important, even when the mere volumetric output was being considered, because a long cutting-edge with a small depth could be obtained as shown in the sketch, Fig. 64. That method of cutting was often used. It gave a very smooth cut and was a useful way of cutting off a large volume of material and producing a fine finish at the same time. In most rough cutting the depth that had to be taken off, if there was to be only one rough cut, was specified; it could not be chosen according to the best conditions of cutting.

The President had already referred to the absence of tests with regard to the effect of variation of top rake. He concluded by saying that it would be very useful if the authors could give, not only sample diagrams of the experimental investigations, but a much larger number of them, because in analysing those investigations different people might take different views as to their interpretation. For instance, he had analysed the curves in a different way from that adopted by Professor Ripper. Only sample diagrams were given, and he had not sufficient data to say, with any degree of certitude, whether his (the speaker's) mode of analysis or the authors' was the better.

Professor **William Ripper**, in reply, said that he could not allow the meeting to close without expressing his warm thanks to the Members for the way in which the Paper had been discussed. He was sorry Mr. Pendred did not see his way to continue his remarks. That gentleman would be interested to know that on the previous evening at Manchester the question raised by him was very much discussed. Summing up the whole discussion, he thought it amounted to the statement that the tests made in the Paper did represent the truth in so far as the limits of the speeds adopted were concerned, but that if the authors had kept the nose of the tool cold, had continued their speeds still lower, and their cuts had been much finer, Mr. Herbert's results would have been arrived at. He had great respect for Mr. Herbert's work, and admired the ingenuity of his machine, but Mr. Burley and himself

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had not come to the same results in their experiments; and as it was the case that many people had a notion that some tool-steels would behave very badly indeed at certain speeds, and would only behave properly at certain other speeds, he thought it was time something definite was done along the lines of ordinary workshop practice to confirm these statements or otherwise. The experience of his colleague and himself, which he thought must be a very common experience, was that there was not that exceptional behaviour; but, as Mr. Herbert himself admitted at Manchester on the previous evening, the results he obtained occurred when the nose of the tool was cold and when it was worked below the speeds included in the present Paper, or in cases of extremely fine finishing cuts and polishing surfaces. The discussion at Manchester was a very interesting one, and he thought the conclusion mutually come to by what appeared to be opposing parties was satisfactory.

He thanked Mr. Roberts for the criticisms he had made. That gentleman had raised a number of points which the members would realize would take a little time to answer, and he therefore proposed to answer them by correspondence. He always valued Professor Smith's criticism and he would study his remarks very carefully, the attachment of which to the Paper as part of the discussion would add greatly to its value.

Incidentally, he would venture to say that he believed there was an increasing respect felt between the workshop and the technical institution. The number of men who had been trained in the technical institutions and who were out in the world taking hold of the world's skilled industries was resulting in a very rapidly growing mutual respect. The practical man, unless he possessed a broad mind, when he looked at experiments carried out in a technical institution was, he feared, a little inclined to sneer; he was a little inclined to think that such work was somehow "playing with it," and that if only the things were done on the scale common in the workshop then they would be of some value. He desired the Members to remember, what he was quite sure they would appreciate directly it was pointed out, namely, that just as the works had its limitations of its own kind in carrying out research work, so also the technical institution was greatly hampered in a similar way. It was impossible for a works, unless it had a special staff and was prepared to spend a considerable sum of money, to carry out extensive research with the necessary degree of accuracy that was desirable under every circumstance. In the same way the technical institutions possessed their limitations. First of all, the teaching staff which did the work was primarily a teaching staff; they had their first duty to perform, the teaching and training of students, and research work was a form of luxury, the kind of thing which was only done when the other work was finished. Then, immediately they came to do the work they met with the difficulty of expense. Directly a little thing was required, however small it might be, money was necessary, and technical institutions were always so poor. Any experiments that it was worth while to carry out involved expense, as those described in the Paper had done. The statement was made in the Paper that a cut of only $\frac{1}{8}$ inch by $\frac{1}{8}$ inch had been made, and he had been asked why the experiments were not made with a $\frac{3}{8}$-inch by $\frac{1}{8}$-inch, or $\frac{1}{2}$-inch by $\frac{1}{8}$-inch cut. He could only refer those who asked such questions to those who held the purse in the technical institutions. (*See* page 1199.)

Mr. G. W. Burley, in reply, said that it had been drilled into the authors so many times in the course of the discussion that the Paper was incomplete, that it was hardly necessary for him to state that the authors were quite aware that they had not covered the whole field of the performance and capabilities of lathe-cutting tools. To cover it completely would take them, if they attempted it, a very long time indeed, as it had taken them a considerable length of time to make the experiments, the results of which were embodied in the Paper. They had reduced the number of variables to a minimum and had worked upon only two or three. To complete the work, it would be necessary to introduce step by step the variables which had been eliminated up to the present time; and that would naturally considerably increase the amount of work which had to be done.

Mr. G. W. Burley.)

With regard to the question of tool nomenclature raised by the President, it should be pointed out that the definitions which the authors had adopted appeared to them to be those which were in common use. They always understood that the top rake was the angle between the horizontal plane and the lip or the top cutting face of the tool measured in the direction of the length of the tool, and that the side rake was the corresponding angle measured at right angles to the length of the tool. That was indicated in the diagrams which constituted Fig. 1 (page 1071).

With regard to the question of the determination of the life or durability of a plain carbon turning-tool, the authors tried quite a number of methods. First of all, they tried to see if they could find a definite point in the life of the tool at which the edge of the tool gave out, or at which a certain degree of bluntness occurred, by merely observing the surface of the work. They were not, however, successful, and had finally to resort to the method which was described in the Paper.

Concerning the measurement of W, it should be stated that the authors had necessarily to adopt an arbitrary standard. The shape of the area which they observed through the microscope was slightly variable, and they tried initially to see if they could measure the average width of it, but they found that they could not do this with any degree of accuracy; and so finally they had to measure the maximum width of the area in a direction normal to the tangent at the cutting edge at the point where this width occurred. He wished the members to understand quite distinctly that it was an arbitrary standard, and that other investigators working at the subject would probably adopt different standards.

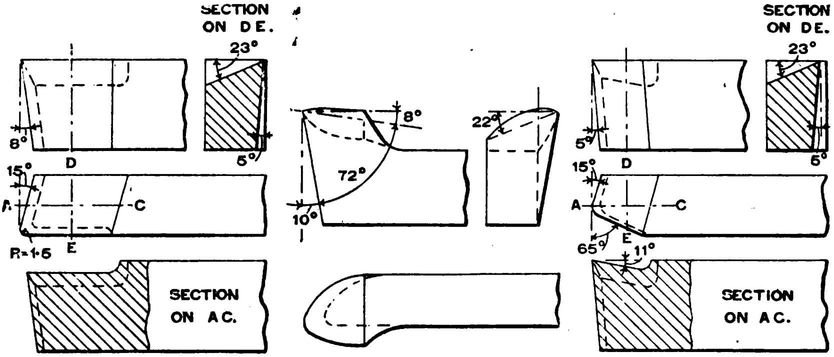
The building up of a new cutting edge on the nose of the tool was really the chief obstacle in the way of the authors in connection with the carbon-tool tests. They had tried several methods to determine the life of a tool, but found that in every case the built-up nose masked the results; and even when they adopted the microscope method they had to remove the built-up nose before the examination of the true cutting edge was possible. To a certain extent, building up also occurred on high-speed tools, though it did not appear to be accompanied by a blunting of the cutting edge as in the case of the carbon tools.

The question of the real significance of "associated" cutting speed had been raised by Mr. Roberts (page 1184) and Professor Smith (page 1187), and a word or two by way of explanation might not be out of place. It did not matter whether it referred to carbon tools or high-speed tools, it was really a standard, though certainly an arbitrary one. What the authors had set out to do was to find the way in which lathe-cutting tools behaved if a definite breaking-down point was assumed in the case of high-speed tools, and a definite kind of blunting in the case of carbon tools. They set a standard of time of sixty minutes, which seemed to them a quite reasonable figure. Mr. Taylor adopted a standard of time, in the first instance, of twenty minutes; whilst the late Dr. Nicolson adopted, at any rate at one time, a standard of about ninety minutes, and so the authors adopted sixty minutes as representing what they thought would be fairly good practice. The "associated" cutting speed was really the cutting speed which was associated with a definite area of cut in order to give a life of sixty minutes to the tool, that is, to produce unit bluntness in sixty minutes in the case of a carbon tool, or to cause the tool to break down in sixty minutes in the case of a high-speed tool. It might be the case that it involved two or three variable quantities, although he did not see that these were other than the depth of cut and feed, because there was a definite life of tool and a standard by which it was measured, either a breaking-down point or a unit amount of wear.

Communications.

Mr. **George W. Goodchild** wrote that, although there were very few firms who had the necessary equipment for deciding the correct shapes and angles suitable for their variety of machines and variety of material to be cut up, yet he believed that the conclusions arrived at by the authors contained some valuable hints for many works managers. At the works of Messrs. Ludwig, Loewe and Co., of Berlin, a series of tests had been made which, though not nearly so exhaustive as those of Professor Ripper, had resulted in very similar conclusions. These experiments were made more in the direction of ascertaining the efficiency and power required by their own lathes, and consequently they did not go into such details as standard bluntness of tool. Their experience otherwise coincided fairly well with that of the authors in regard to the most favourable shape of the cutting tool. These tests were made in three series of six tests, and three different shapes of turning tools were used, Fig. 65. The procedure at these tests was systematically to change the tool, the cutting speed, the depth of cut and the feed whilst the area of the cut was kept constant.

Fig. 65.—*Three Tools, used in Testing Efficiency and Power of Lathes.*



Suitable for great depth of cut.

Used for big feeds.

Suitable for deep cuts with low feeds.

The conclusions they arrived at from these tests were the following:—

(1) It was essential that the cutting speeds should be neither too high nor too low, and to help the operator they had tabulated these correct cutting speeds for various types of machines and the different materials. The best cutting speed in their tests was 22 metres per minute.

(2) Shape of the first tool was more suitable for great depth of cut, and less suitable for small depth of cut at high feeds.

(3) Round-nosed tools (Taylor pattern) were more favourable for big feeds, and would then stand greater cutting speeds whilst using more power for the same amount of cut-up material.

(4) Uniformly good results were obtained from the third tool. The specific consumption of power remained almost constant under varying conditions, though the best results were obtained when deep cuts at low feeds were taken.

The Authors wrote that, in replying to the President's remark in regard to the angles of the tools (page 1177), it should be pointed out that these were amongst the variables which were eliminated in the tests. It was not suggested, however, that the angles selected were those which were the most suitable for every class of metal. On the other hand, it was readily admitted that other angles were more suitable for the harder grades of steel, but to have varied the angles would have complicated the investigation.

Referring to Mr. Roberts' remarks (page 1183), the ammeter reading method was not tried because the small lathe on which the carbon-tool tests were made was not electrically driven, whilst with the high-speed tools the direct breakdown method was available. It was probable, however, that the ammeter method would not be very serviceable with comparatively light cuts, because under such circumstances the power required to overcome the tool resistance was usually much less than that required to drive the machine, with the result that a slight change in the amperage would hardly be noticeable. Again, ammeters in machine-tool motor circuits were

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not usually very dead-beat, which increased the difficulty of detecting any slight sudden change.

Concerning the value of the exponent in Equation 1 (page 1083), it should be stated that exponent 5 was the correct average value for all the curves which were drawn, but some of which were not published, whilst Mr. Roberts' value of 6 was only true for the curve selected by him. The relation between the volume of material removed and the associated cutting-speed for any given area of cut, for carbon-steel tools, worked out at $V = \frac{\text{constant}}{S^4}$.

The Brinell and scleroscope tests for hardness had been used, but were abandoned in favour of the tensile test.

Professor Robert H. Smith and other speakers were in doubt as to the possibility of measuring accurately the width of the worn surface by the method shown in Fig. 2 (page 1073), but in actual practice there was no difficulty, as the worn surface was very distinct, the line of demarcation between the blunted portion and the remainder of the tool being perfectly clear. The blunted surface always showed a bright polish, while the adjoining surface was of a dull colour. It was admitted that the method was not ideal, but pending the discovery of a more satisfactory one they were disposed to continue the present method. The method suggested by Professor Smith was a good one, but the authors were doubtful whether the results obtained with it would be more accurate than with their own method. The authors appreciated the point raised by Professor Smith in regard to the expression of the curves by suitable formulæ, and they recognized the merit of the form as given by him.

Professor Smith and other speakers regretted that the Paper did not cover a larger field and that it left out a great deal that was of extreme importance. The authors recognized that the work done touched not much more than the fringe of the subject, and that there was a wide field of work yet to be covered. This remark covered the question of "dry cutting versus lubrication," but for the purposes of comparative tests the dry form of testing was more convenient, as well as shorter in duration. The relation between dry and wet cutting was a large question and was worthy of a separate Paper dealing with that question only. The output was given in weight or volume, and the authors had in their minds roughing cuts and not finishing or polishing cuts.

In reply to Mr. Christopher James (page 1142), the authors admitted that the cuts made by them in these tests were small, but when due correction had been made for the area of tool-steel employed, they thought they would be found comparable in their results with the large cuts referred to in heavy forge or gun work. They agreed that if the tests had been made under profuse lubrication, instead of dry, the output would have been increased.

Mr. Alfred Saxon (page 1143) took exception to the authors' remark that there was very little information readily available as to the definite measure of the output of work of which lathe tools were capable. The authors' point was that while there was a vast mass of information in the possession of machine-tool users, it was not readily available in the same sense as was the case in other branches of practical engineering, mechanical, electrical and civil, where the results of experience and experiment had been reduced to an exact science. There was, even at the present time, much difference of opinion among practical workers of large experience on many matters connected with machine-tool work, chiefly because the results of experience had not been collected and correlated and made available for general use in the same way as was the case in other branches of engineering. The authors desired that their Paper should be considered as a small additional contribution to the literature of cutting tools, and they considered that a good discussion on the subject, as in the present case, was one of the best means by which such information could be collected and made available.

Mr. Allingham (page 1144) thought that the authors should have had continually in their minds in carrying out these researches "what steps must be taken in the ordinary engineering factory to enable quick and certain use to be made of the scientific data being obtained." The authors agreed that this was the ultimate purpose of all such work, but they submitted that if the researchers in

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steam, gas, oil and electrical engineering had worked in the spirit of eager haste for immediate results, the science of these subjects would have been far less complete than it was to-day. The Paper only dealt with a small part of the subject, and it was not wise, they thought, too readily to deduce general conclusions for immediate practical application before all the variables involved had been fully considered.

Mr. E. G. Herbert (page 1150), in criticising the method of measuring bluntness, considered that the width of the worn surface depended to some extent on the thickness of the chip. This was no doubt true, but it did not affect the relative value of the curves drawn, because each series of tests was made under a constant condition of thickness of chip. The authors admitted Mr. Herbert's objection to the removal of the tool from time to time for the purpose of measurement, but it was difficult to see how the measurement could have been made in any other way, and in any case they believed the possible error introduced to be extremely small. An attempt was made to measure the wear of the tool by measuring the difference in the diameter of the work before and after the cut, as suggested, but it was found impossible to measure differences of diameter with sufficient accuracy to be of any value as a means of measuring bluntness.

Mr. Herbert stated that the phenomenon of "reduced durability at reduced speed" could only take place when the cutting point of the tool was practically cold, and that, in order to find it, it was further necessary that the cut employed should be twenty-seven times less in area than any of the cuts actually used in the authors' tests. The phenomenon, in fact, was apparently confined to very fine cuts with water-cooling, and as such cuts were not, as Mr. Herbert said, included in the authors' tests they had no objection to the modification of their conclusion as suggested, and the words "within the limits of their experiments" had been added to the conclusions above referred to. If no other fact had resulted from the discussion of the Paper, the explanation given by Mr. Herbert of the reason why the authors had failed to find the phenomenon referred to, namely, reduced durability at reduced speed, was sufficient reward to them for their work, because this explanation ruled out the appearance of the above phenomenon from workshop conditions corresponding with those set forth in the Paper, and made it clear that they were not of universal application, as appeared to have been claimed by Mr. Herbert in describing the uses of his tool-steel testing machine. The authors had always admitted the possibility of Mr. Herbert's results under certain conditions, but it was the question of their general application which required clearing up.

Referring to Mr. Herbert's very curious diagram, Fig. 54 (page 1153), the curve which returned towards zero must at any rate return upon itself again very soon and continue its original path, otherwise it would appear to show that at zero speed it would produce zero durability, or, in other words, that the tool was worn out before it commenced to cut. Mr. Herbert pointed out that in the diagram he submitted, Fig. 54, he had taken fourteen different cutting speeds, whereas the authors had only taken four cutting speeds, and suggested that if the authors had taken points at intermediate speeds they also would have obtained an irregular curve; but it should be pointed out that the speeds in Mr. Herbert's tests ranged from 20 to 150 feet per minute, whereas the range in the authors' tests was very much less, not exceeding in some cases a total of 20 feet. Even with his fourteen readings Mr. Herbert's range between each reading was 10 feet. The authors' range was an average of 5 feet.

The curves shown by Mr. Herbert in the course of his remarks gave plottings of results obtained by him with speed as ordinates and durability as base, but it would be noticed that the durability scale was not a scale of time but of inches of tube turned away. But length of tube was not a suitable criterion of durability unless each inch of tube was turned off in the same time. Since the revolutions of the machine were varied, from a high range down to a low range, the rate of cutting was a varying one, and inches of tube in these circumstances did not seem to be a correct measure of durability. Assuming the feed per revolution to be constant, it was possible to convert Mr. Herbert's curve into a curve drawn

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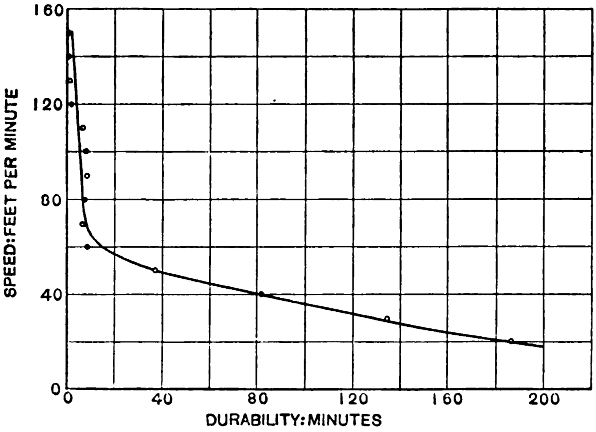
upon a true time-base. Such a curve was shown in Fig. 66, which was reproduced from Mr. Herbert's curve, Fig. 54. It would be noticed that the irregularity almost disappeared, and the turn backwards of the curve at the right-hand corner given by Mr. Herbert did not occur on the true time-base curve, but became merely a continuation in the same direction of the portion of the curve immediately preceding it. The dots were the points of measurement taken from Mr. Herbert's curve. It was not suggested, however, that all Mr. Herbert's curves lost their irregularities when converted to a true time-base, but in the case of Fig. 54 the irregularities as stated did so disappear.

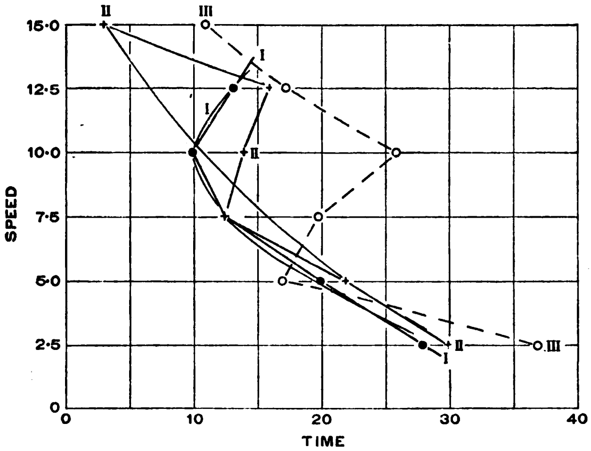
Fig. 66.—*Mr. Herbert's* 14 *Observations* (Fig. 54, page 1153) *plotted to a Time-Base.*



With reference to the form of the formulæ expressing the relation of speed to depth and feed, the authors' formulæ were deduced directly from the average curves of performance as plotted from their own experiments, and represented the nearest practical expressions suitable for general use. The exact equation to the average curve was given in Formula 6 (page 1103). Formulæ 7 and 8 were a slight modification of this. It was of interest to the authors to find that Mr. Herbert's deductions made by him from Mr. Taylor's results were practically identical with those which they obtained from their own independent experiments; but Mr. Herbert's deductions had never been considered by the authors until their attention was called to them at the Meeting.

With reference to the curves submitted by Mr. Herbert representing experiments made by Professor Poliakoff, whose able work was well known, the authors had replotted the diagram made by Mr. Herbert (Fig. 53, p. 1153) on a speed-time base, Fig. 67, and while the diagram showed irregularities it could hardly be said to show "in every case increasing durability at increasing speed," for the major portion of it showed quite the opposite tendency. The irregularity was, however, worthy of careful note, and confirmed in some measure the results obtained by Mr. Herbert. They were, however, the result of tests made with a depth of cut $\frac{1}{200}$ inch and a feed of $\frac{1}{72}$ inch, which conditions were outside those described in the authors' Paper. For the experiments represented by the line marked No. I in Fig. 67 no test appeared to have been made at the higher speed of 15 units, otherwise the line would presumably have returned to a low durability, as in the case of those marked II and III.

Fig. 67.—*Mr. Herbert's Curve* (Fig. 53, page 1153) *plotted to a Speed-Time Base.*



(The Authors.)

Mr. Brayshaw's remarks, also those made by Mr. Nelson, were much appreciated by the authors, and they wished to say in reply that it was their intention to continue their work on the performance of cutting tools.

Mr. Dempster Smith's reference to measurement of bluntness was dealt with in the reply to Professor Robert H. Smith (page 1200), and in regard to the presence of the small pile of shavings on the nose of the tool and its effect upon the result when considered along with tools where this phenomenon did not occur, it was found in practice throughout the trials that the false nose was invariably present in the carbon-tool tests though not so in the high-speed tool tests. Mr. Dempster Smith stated (page 1161) that the formula given by the authors for cutting speeds at given areas was below that usual in practice, and a Table was given showing that this difference was very considerable. It should, however, be pointed out that only about the first three values in the Table were applicable, because the equation gave the speeds at which a tool of ¾ inch by ½ inch should be run. Mr. Dempster Smith would hardly take a cut 1 inch deep and ¼ inch feed with a ¾-inch by ½-inch tool. The authors regretted that it had not been made sufficiently clear by them in the Paper that the formulæ were expressions for the performance of the standard tool which they used throughout the tests, namely, a ¾-inch by ½-inch tool, and that the use of a factor was necessary in cases where the area of cut taken was outside the range of the tests made by this tool. Heavier cuts than those given in the Paper, with their appropriate speeds for maximum output, would be taken with tool-steels with correspondingly larger section and correspondingly increased radius of nose, and equations were given below embodying these factors for more general application.

In the Table given by Mr. Dempster Smith (page 1160) the speeds for carbon tools appeared to be somewhat high, but the authors admitted that, owing to the choice of a too low standard of bluntness, the values given by their equation appeared to be low, and that they required to be increased in the ratio of $1:1{\cdot}5$ for carbon tools. Equation 4 (page 1090) would then become

$$S = \frac{(67-T)\times 0\cdot 028}{\sqrt{A}}.$$

If the above equation were made a general one by including in it the factor due to the effect of tool-steel section on maximum output, then

$$S = \frac{(67-T)\times 0\cdot 035\sqrt[4]{a}}{\sqrt{A}}$$

for carbon tools, where S = associated cutting speed in feet per minute, A = area of cut in square inches, and *a* = area of tool-steel section in square inches with proportionate nose-radius.

The general formula for the value of S for maximum output for high-speed tool-steel sections, including the effect of sectional area of tool-steel and corresponding appropriate radius of tool, became

$$S = \frac{(65-T)\times 0\cdot 244\sqrt[6]{a}}{\sqrt[3]{F^2D}} \text{ for high-speed steels.}$$

An Appendix (page 1209) was attached to the Discussion, showing the derivation of the above general formulæ.

Mr. Dempster Smith stated that the durability of the tool was independent of the tool-steel section (page 1162), and that the increased output obtained by the authors from tools of different sections was due, not to the difference of section, but to the radius of the nose of the tool only. This statement was a striking example of the need of further investigation of the subject of tool-steel performance, as in the authors' opinion practical experience was not in agreement with this conclusion, but that, in any set of conditions aiming at maximum output, area of tool-steel section was an important factor, heavier depths and feeds being possible as the tool-steel area increased. Their own results showed that for tools of a constant nose-radius but with variable sectional area of tool-steel, there was an increased maximum output, due to the heavier cuts possible with increased area of the tool-steel; and that with tools of a constant section but variable nose-radius there was an increased maximum output also due to increase of the radius of the nose. The total output factors

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for varying area of tool-steel, as given by the authors, Fig. 40 (page 1113), remained unaffected for the conditions described in the Paper, namely, geometrical similarity in the shape of the nose, it being understood, however, that the output factor was made up of two parts, first that due to the tool section, and secondly, that due to the radius of the nose appropriate to that section.

The diagrams prepared by Mr. Daniel Adamson (page 1168), comparing the performance of the 1¼-inch square tools used in the Manchester tests with the ¾-inch by ½-inch used in the Sheffield tests, did not illustrate the fact that the authors showed in their Paper that area of tool-steel section had considerable effect upon the output in any set of conditions aiming at maximum output. Before a fair comparison could be made between the performance of the 1¼-inch square Manchester tools and the ¾-inch by ½-inch Sheffield tools, the Sheffield results must be multiplied by the factor due to the influence of the tool-steel section as described on page 1114. If this factor of output were used, it would be found that the Sheffield curves would, as nearly as possible, coincide with the Manchester curves. The authors admitted that they had not made it sufficiently clear that this correction was necessary.

With reference to Mr. Adamson's remarks as to the cost of the Sheffield lathe and his disappointment that more work had not been done with it, it should be stated that the purpose of this lathe was a very definite one, which was not primarily to produce Papers such as was now being presented, but to do the regular daily work of the Department, namely, to test the various qualities of tool-steels made by the metallurgical students in the steel foundries of the Applied Science Department of the University for the information and training of the students. The production of Papers, such as the one submitted, was entirely an honorary matter, and was done outside the ordinary duties of the Department. The curves in Fig. 29 (page 1099) were based upon the average results obtained. The cuttings in the tests were not weighed, but the expression of output in cubic inches was the result of minute and careful measurement.

Mr. E. Millington (page 1172) called attention very properly to the absence of information on the question of hardening or composition of the tool-steels, but he would understand that within the limits of the Paper it was impossible to deal with so wide a subject.

Appendix to Authors' Reply.

Showing the derivation of the Formulæ referred to in the Authors' written Reply.

1. *Carbon Tools.*—

Let S = the cutting speed;

A_1 = the associated area of cut for a standard tool ($\frac{3}{4}$ inch × $\frac{1}{2}$ inch section); and

A = the associated area of cut for a tool a square inches in cross-section, with its proportionate nose-radius.

Then—

$$S = \frac{(67 - T) \times 0{\cdot}028}{\sqrt{A_1}} = \frac{(67 - T) \times K_a}{\sqrt{A}},$$

from which we derive the expression—

$$K_a = 0{\cdot}028 \sqrt{\frac{A}{A_1}}.$$

From Formula 14 (page 1114) we know that, for a constant cutting speed as above—

$$D = \text{constant} \times \sqrt{a}.$$

Therefore, since the feed is constant also—

$$A = \text{constant} \times \sqrt{a}$$

and

$$A_1 = \text{constant} \times \sqrt{\frac{3}{8}}.$$

Whence—

$$\frac{A}{A_1} = \sqrt{\frac{8a}{3}}$$

and

$$\sqrt{\frac{A}{A_1}} = \sqrt[4]{\frac{8a}{3}} = 1{\cdot}27\sqrt[4]{a}.$$

That is—

$$K_a = 1{\cdot}27\sqrt[4]{a} \times 0{\cdot}028 = 0{\cdot}035\sqrt[4]{a},$$

and

$$S = \frac{(67 - T) \times 0{\cdot}035\sqrt[4]{a}}{\sqrt{A}}.$$

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2. *High-Speed Tools.*—

Let F and D_1 = the feed and depth of cut respectively for a standard tool ($\frac{3}{4}$ inch × $\frac{1}{2}$ inch) associated with the cutting speed S: and

F and D = the same data for a tool *a* square inches in cross-section.

Then—

$$S = \frac{(65-T)\times 0\cdot 207}{\sqrt[3]{F^2 D_1}} = \frac{(65-T)\times K_a}{\sqrt[3]{F^2 D}},$$

from which it follows that—

$$K_a = 0\cdot 207\sqrt[3]{\frac{D}{D_1}}.$$

As before,

$$D_1 = \text{constant} \times \sqrt{\frac{3}{8}}$$

and $$D = \text{constant} \times \sqrt{a}.$$

Whence, $$\frac{D}{D_1} = \sqrt{\frac{8a}{3}},$$

and $$\sqrt[3]{\frac{D}{D_1}} = \sqrt[6]{\frac{8a}{3}} = 1\cdot 18\sqrt[6]{a}.$$

That is—

$$K_a = 0\cdot 207 \times 1\cdot 18\sqrt[6]{a} = 0\cdot 24\sqrt[6]{a},$$

and $$S = \frac{(65-T)\times 0\cdot 24\sqrt[6]{a}}{\sqrt[3]{F^2 D}}.$$

"THOMAS HAWKSLEY" LECTURE.

The FIRST "THOMAS HAWKSLEY" LECTURE on "Water as a Mechanical Agent" was delivered by Mr. EDWARD B. ELLINGTON, *Past-President*, at the Institution, on Friday, 5th December 1913, at Eight o'clock p.m.; Sir H. FREDERICK DONALDSON, K.C.B., *President*, in the Chair.

The PRESIDENT said that the occasion of the Meeting that evening was a twofold one; in the first instance it was the inauguration of a series of Lectures, and in the second place it served as a memorial to the late Mr. Thomas Hawksley, F.R.S. Mr. Thomas Hawksley, as the Meeting was aware, was President of the Institution in 1876–77, and it was owing to the generosity of his son, Mr. Charles Hawksley, that the Council had been enabled to render this twofold service to the Institution, and to assist in the dissemination of useful knowledge by experts, in the form of Lectures. On behalf of the Institution, he was quite sure that he was right in expressing on that occasion their deep gratitude to Mr. Charles Hawksley for his generosity. He personally was most grateful to Mr. Charles Hawksley, because the institution of these Lectures shed a lustre upon his term of office which it would not otherwise have had. It was most fortunate that the first of these Lectures should be delivered by so great an expert in hydraulic engineering as their dear friend, Mr. Ellington. They all knew what he had done for the Institution, and they had an evidence that evening of his readiness, although he had passed the Presidential Chair, to continue, as he continued in the Council Room and in the Committee Room, to look after the interests of their great Institution. He would not detain the Meeting any further, but would ask Mr. Ellington to proceed to deliver his Lecture.

(The Lecture was then delivered by Mr. Ellington.)

The **President** said he had opened the proceedings by congratulating the Institution on having secured Mr. Ellington to deliver the first of these Lectures. He was quite sure they would agree with him that those congratulations in anticipation were not misplaced, and they were not misplaced now that they had heard the Lecture. He would ask the Meeting to accord to Mr. Ellington a most cordial vote of thanks for all the trouble he had taken in conveying their thoughts from the first principles, when poisoned water was what people lived upon, down to the present time, when they could not stand a microbe; and from taking them from the natural power of the rain to the great press they had just seen. He would ask them to accord that vote of thanks with acclamation, and he would also ask Mr. Ellington to be good enough to allow his Lecture to be printed and included in the Proceedings of the Institution.

Mr. **Edward B. Ellington** (Past-President) thanked Sir Frederick Donaldson and all those present for their very kindly expressed appreciation of his efforts in a new departure. He undertook to deliver the Lecture with considerable hesitation, and if it had not been for the special information he had obtained, he would certainly not have been able to write a great deal of that which they had heard. He would therefore take the opportunity to acknowledge the assistance which he had received in the preparation of the Lecture which they had so kindly listened to.

Mr. **CHARLES HAWKSLEY** (Member of Council) asked the President's permission to take that opportunity to acknowledge publicly his very deep indebtedness to Mr. Ellington for having so kindly undertaken to deliver the first of these Lectures, also for the manner in which he had discharged that duty. He desired to tender him his very best thanks, and he was obliged to the President for giving him the permission to do so.

RECEPTION.

After the Lecture, a **RECEPTION** was held by the **PRESIDENT** and **LADY DONALDSON**, which was attended by over 600 Ladies and Gentlemen. During the evening vocal and instrumental music were given in the Library, and a number of pictures of engineering interest, including Irrigation in Egypt by Sun Power, were shown on the Cinematograph.

The LECTURE was repeated by Mr. ELLINGTON on the following occasions:—

At BIRMINGHAM, in the Medical Lecture Theatre of the University, on Thursday, 22nd January 1914. Sir GERARD A. MUNTZ, Bart. (*Member of Council*), presided, and 92 were present.

At LEEDS, in the Philosophical Hall, on Wednesday, 28th January 1914. Mr. J. HARTLEY WICKSTEED (*Past-President*) presided, and 74 were present.

At LIVERPOOL, in the Engineering Theatre of the University, on Friday, 30th January 1914. Mr. JOHN A. F. ASPINALL (*Past-President*) presided, and 111 were present.

At NOTTINGHAM, in the University College, on Wednesday, 11th February 1914. Mr. WILLIAM H. PATCHELL (*Member of Council*) presided, and 91 were present.

[Arrangements have been made for the delivery of this Lecture before the CALCUTTA AND DISTRICT SECTION.]

"THOMAS HAWKSLEY" LECTURE.

WATER AS A MECHANICAL AGENT.

BY EDWARD B. ELLINGTON, *Past-President.*

FRIDAY, 5TH DECEMBER 1913.

Scope of Lectures.—When the Council of the Institution of Mechanical Engineers decided, with the approval and through the liberality of Mr. Charles Hawksley, to establish the "Thomas Hawksley" Lecture in memory of our distinguished Past-President, it was thought appropriate that the first Lecture should deal with some subject germane to Thomas Hawksley's work from the point of view of mechanical engineering, and that generally the choice of subjects for the Lectures should, as far as practicable, have reference to those branches of engineering with the development of which Thomas Hawksley was mainly concerned. The title of this Lecture shows that the Council are prepared to give a fairly wide interpretation to this desire.

However this may be, you will, I am sure, all agree that it is only fit that I should first of all recall to your recollection the life work of Thomas Hawksley. He was *the* waterworks engineer of the great Victorian Era, and his pre-eminence has been universally acknowledged.

Water Engineering 100 *Years Ago.*—What was the position of water engineering less than a century ago? It is somewhat startling to realize, for instance, that the water supply of London was then mainly drawn from the tidal water of the Thames. Old London Bridge was still standing, having been erected in the 13th century. There was a drop of 4 feet owing to the obstruction of the arches, and in the 16th century Peter Morrice, a Dutchman, had placed undershot water-wheels and pumps under some of these arches.* There was no main drainage in 1813; cholera was rampant a few years later, and the science of hygiene was practically non-existent. It is true that this lamentable state of affairs was not acquiesced in without severe criticism. In a pamphlet published in 1827 it was stated that "The water taken up from the Thames between Chelsea Hospital and London Bridge was charged with the contents of more than 130 common sewers, the drainage from dunghills and laystalls, the refuse of hospitals, slaughter-houses, colour, lead, gas and soap works, drug mills and manufactories, and with all sorts of decomposed animal and vegetable substances, rendering the said water offensive and destructive to health, and ought no longer to be taken up by any of the companies from so foul a source."

The New River of Sir Hugh Myddleton, a pure water supply, was inaugurated 300 years ago. The East London Water Company was established in the year of Hawksley's birth. The Southwark and Vauxhall Company had its origin in the London Bridge Waterworks. The latter were, however, acquired by the New River Company in 1822, and the supply from this source was soon after abandoned. The West Middlesex Waterworks operations were of considerable extent at this date, and the Grand Junction Works were established at about the same time. The Lambeth Waterworks supplied a considerable quantity south of the Thames. The Chelsea Waterworks served a large area on the left bank of the river. All these works are now merged into the Metropolitan Water Board.

In London in 1827 it is evident that is was quality rather than quantity that was deficient. The advantage, and indeed the necessity, of an abundant and constant supply of pure water to the inhabitants of large cities had been realized in the earliest times of which records remain, but the experience gained by the earlier nations was lost during the breakup of the ancient civilizations. Rome is supposed to have had a supply of 38 million gallons daily for

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* Figs. 1 and 2.

FIG. 1.—*Old London Bridge*, A.D. 1700. (Encyclopædia Britannica, 1898.)

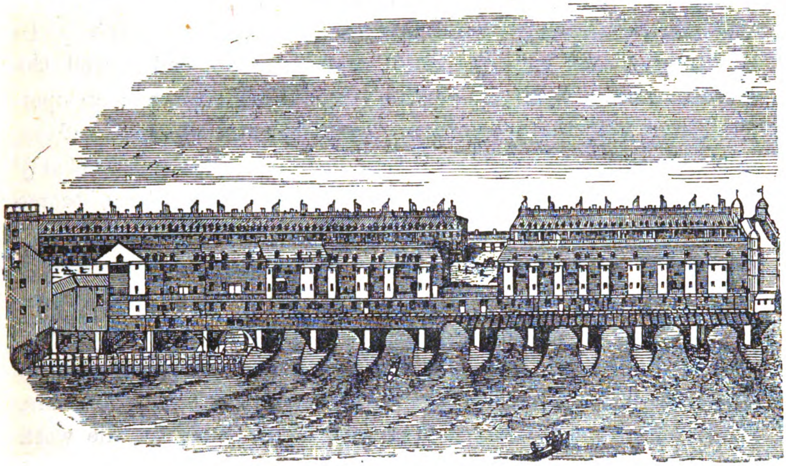
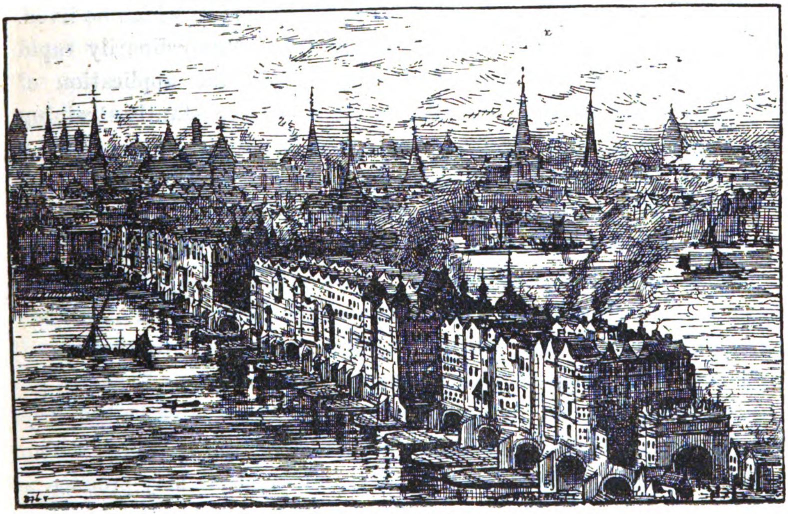


FIG. 2.—*Old London Bridge*. (Thames Bridges, J. Dredge.)



its population of one million, but for a thousand years or more the Western World appears to have been generally oblivious to the appalling evils arising from defective water supply and drainage in thickly populated areas. Even I myself can remember well the horrible cholera times in London when the Thames was an open sewer, and half the people were drinking water which, nowadays, would be considered totally unfit for human consumption. Probably the majority of the inhabitants had, in the course of centuries, become immune, and the consequences, except in times of epidemic, were not so disastrous as would be the case to-day under the stress of such a state of affairs. The difference between then and now demonstrates the extraordinary advance that was made during the lifetime of Thomas Hawksley and other distinguished engineers of the last century, and justifies the veneration of their successors. We owe to them an ungrudging debt of gratitude for the work that they accomplished, notwithstanding little experience and even less formulated scientific knowledge available for their guidance. Such names as Simpson, Bateman, Chadwick, Mansergh, and others are household words in this branch of engineering; but foremost amongst them was Thomas Hawksley, who will ever remain a representative of the age in which he lived. As you all know, this age was marked by extraordinarily rapid improvement in the mechanical arts, and in the application of science to the needs of a population which was constantly straining to breaking point the visible means of sustaining its life.

Men of every generation are influenced by their environment. But, while the environment determines the direction of their activities, it has little to do with their essential characteristics in relation to their contemporaries. Great men in every walk of life and in every age have, I venture to say, always been men of greater imagination than their fellows. Imagination is the touchstone of genius; but if genius is to secure recognition and prove its existence there must be something added. There must be industry and practical ability, which is the power of applying knowledge and experience. Without the latter, imagination may produce a dreamer, but certainly not an engineer.

The Engineering Education of Thomas Hawksley.—In the early part of the 19th century the profession of engineering was in quite an unorganized condition. Engineers were born, not made, and Thomas Hawksley's early training in engineering was characteristic of the period. He was born near Nottingham in 1807, his father being a manufacturer in that town. He was educated at the old Grammar School in Nottingham, and at the age of fifteen was apprenticed to an architect and surveyor, subsequently becoming a partner in the firm whose business included what would now be considered engineering construction. Diligent and active in the pursuit of knowledge, Hawksley acquired through private study an intimate knowledge of mathematics and the science of the day in matters appertaining to engineering, and in that way qualified himself, as far as circumstances permitted, to carry out such works as came to his hand. At that time there was no more prolific field for his energies than waterworks.

Constant Supply.—In common with most cities and towns in the Kingdom, Nottingham was suffering from an insufficient and impure water supply, and Hawksley's first work of importance consisted in the construction of the Trent Waterworks.* The water was pumped from the gravel and sandbeds of that river and supplemented the existing supply from the River Nene. At this time Hawksley was just 23 years of age, and the activity of his mind and confidence in his own judgment were even then displayed both in the opinions he expressed and in the determination with which he carried his opinions into practice. His advocacy of the system of constant supply of water to the consumers may be said to have revolutionized the methods adopted for water supply throughout the United Kingdom. From the earliest times water had been conveyed to the towns, but its distribution had been left to the inhabitants. At the public fountains a constant flow was usually secured, and to this system is due much of the picturesqueness of mediæval cities. The original works of the New River Company were executed on this plan and the trade of water carriers flourished under the system. It was only in comparatively recent times that a demand arose for detailed distribution through a general network of mains to individual consumers, and the established procedure at the time of the construction of the Trent Works was to give an intermittent supply into cisterns at consumers' houses, a system of much inconvenience and danger to health. In the face of great opposition and many difficulties, Hawksley stuck to his guns, and in the end his views were completely justified. The system of constant supply is now taken as a matter of course in all well-equipped waterworks undertakings.

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* Fig. 3, Plate 37.

The Liverpool Works.—In 1852 Hawksley moved to London, and had the satisfaction, during his career, of establishing at least 150 waterworks at home and abroad, one of the largest at the time of construction being the Rivington Works at Liverpool, 29 miles from that city. He was engaged subsequently as Engineer-in-Chief upon the great modern works at Vyrnwy for the supply of Liverpool. These later works were proposed by the late Mr. G. F. Deacon, the then Water Engineer of the Corporation of Liverpool. Mr. Deacon acted with Mr. Hawksley, and on the latter's retirement became entirely responsible for their execution. (A model section of the Vyrnwy masonry dam was exhibited, having been kindly lent to the Lecturer by Mr. Charles Hawksley.)

Hawksley's Uniform Success, and its Causes.—The outstanding fact in connection with Hawksley's work was its uniform success. It falls to the lot of few engineers to have had such a record. Failure to Hawksley was an unknown quantity. This was due to the great care exercised by him in the preliminary stages of his works, to his high scientific attainments, to the uniform solidity of his designs, and to unswerving adhesion to his principle that cost was after all a secondary consideration in the construction of works which were to last for generations. An unreasoning desire for cheapness without regard to the risks involved, so characteristio of the present day, was to him an abomination. It is possible that his early architectural training may have led him to design buildings which to some may have savoured of too much ornament, but as a fine picture is worthy of a well-executed and beautiful frame, so the fine plant of a modern waterworks is worthy of a fine house. All will agree, I think, that as engineers we have, as a class, been too indulgent, in engineering structures, to the absence of beauty of form, and have allowed utilitarian conceptions to prevent adequate consideration being given to the stimulating influence of making our work pleasant to the eye as well as being mechanically adapted to its purpose.*

Hawksley, a Leading Gas and Drainage Engineer.—Waterworks, however, were not the sole outlet for Hawksley's energies. He became one of the leading gas engineers of the last century.† Gas supply was first established in London in the year of his birth, and it was in Nottingham again that his first gasworks were erected. He was, moreover, the first President of the British Association of Gas Managers, founded in 1864. It is interesting to record as showing his character, that during the Chartist riot at Nottingham he successfully turned the table on the mob by his spirited defence of the works. Hawksley also carried out many main drainage works, and in conjunction with Mr. Bidder and Sir Joseph Bazalgette, who received his knighthood later, was instrumental in the establishment of the main drainage system of London. He was, as you well know, President of the Institution of Civil Engineers as well as of this Institution. In 1876 he was President of the Health Section of the National Association of Social Science, and gave a remarkable Address dealing largely with the statistics in relation to sanitation, which is well worth perusal at the present time.

Defects in present System of Training Engineers.—Before I leave the subject of Thomas Hawksley's career, I should like to give prominence to the fact of the very early age at which he had responsible charge of undertakings. It seems to me that the great defect of our present method of training engineers is that the positions of responsibility are taken at too late an age. If a man nowadays is to have a good general education, followed later by a college course in engineering, and further on, adequate practical training, it is almost impossible for him to have any really responsible work to do until he is well over 25 years of age. Without responsibility, real experience cannot be gained. Experience of the past may be acquired, but knowledge acquired by study alone is insufficient. No man can fully come to his own, or show what he is capable of, until he is thrown on his own resources, and the problem yet unsolved is how to combine adequate training with early responsibility. The present system may lead to fewer failures, but it may also produce stagnation. At the present moment, I admit, there are no signs of the latter, but let us not forget that we are still under the influence, and are reaping the experience, of men of the older school. It is a serious question for the rising generation. Possibly all that can be done is to impress upon all young engineers in course of training for the profession the fact that all their school and college training is but crossing the threshold of their life's work, and that unless such training is supplemented by continued practical experience in positions of considerable responsibility, there is great danger that they will find themselves passed by the practical man who has not had their advantages. Genius may, of course, triumph over all difficulties, but those we have to consider most are youths of average ability. Engineering is a profession in which there are few prizes and many blanks, and our training should be such that if the former cannot be gained, at least an honest competence can be secured commensurate with the sacrifices involved in such training.

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* Fig. 4, Plate 37.

† Fig. 6, Plate 37.

Thomas Hawksley possessed in a large measure the essential characteristics of a great man, and I have not in any way overstated the services he rendered to his generation, or the lessons to be learned from his long and honoured career.*

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* For Portraits, *see* Frontispiece and Fig. 7, Plate 37.

WATER AS A MECHANICAL AGENT.

The title I have given to my Lecture is "Water as a Mechanical Agent." It may seem at first sight that I am here parting company with Thomas Hawksley's special work, but a little consideration will show that in fact the departure is more apparent than real. It is granted that Thomas Hawksley's work was mainly in the direction of giving to towns a wholesome and efficient supply of water for the purpose of domestic consumption, but it is evident that, before a general supply of water can be made available for domestic use by a community, its mechanical aspect must be considered and mechanism of some sort must be provided. The greater the area and the population to be served, the more efficient and complicated must be the mechanism employed, and the more thorough must be the co-ordination between such mechanism and the physical properties of the water itself.

Flow of Water in Pipes.—Water at rest in a pipe or cylinder produces a pressure on its supporting surfaces in proportion to its depth from the free surface or head. When the water is in motion a portion of the head is expended in producing the velocity. The relations between head, pressure, and velocity are fundamental, and must always be borne in mind in connection with hydraulic work. Our knowledge of the actual flow of water through pipes and orifices is empirical, and I wish to convey a warning, especially to the younger engineers, that without experience it is most unwise for them to rely entirely on the formulæ which have been devised from experiments obtained under conditions which are, as a general rule, not realizable in practice.

The frictional loss in the flow of water along a pipe-line has been determined for ordinary velocities in hydraulic works with great accuracy, but on the assumption of the pipes being clean and of uniform diameter. The experimental pipe, of which I am speaking, has a smooth and true surface, and the ordinary formulæ for the flow are true within a very small limit of error for the assumed conditions, and provided the velocity of flow does not exceed, say, 50 feet per second. Research is now in progress at the National Physical Laboratory at higher velocities.

The actual pipes as laid are made up of a number of small sections of a few yards in length and with many irregularities. Now, every variation of the smooth and even surface, especially when considerable velocities are employed, sets up eddies, the effects of which are indeterminate and render inapplicable the results obtained from the flow in the smooth and uniform pipe. I am aware that many experiments have been made with long lengths of pipes with encrusted surfaces and other obstructions, in which the resistance is often double that of a new clean pipe. Such experiments show the importance of the personal equation in their application.

In designing hydraulic works, as in others, there is no more useful maxim to be kept in mind than that a sharp corner, or any sudden change of section, is a blemish, and may lead to disastrous results, even when the most recent and approved formulæ have been used for the calculations.

In my own experience I have constantly found it necessary to bear in mind the distinction between a theory stable enough when supported on its ashlar pedestal of assumptions, but insecure when placed on the rubble foundation of the actual work in hand. It will then quite probably prove a fallen idol.

Pumping Engines.—Water when used as a mechanical agent always involves either its flow from a higher to a lower level, or a fall from a higher to a lower pressure. The former is characteristic of a gravitation supply, while the latter usually depends upon pumping. In some cases, part of the energy due to the fall is used for pumping, as in the case of the ordinary hydraulic ram, but as a rule some agent other than water, such as steam, is adopted.

Water was probably the first mechanical agent used by man. One hears a good deal about the power of the tides, but it is, I think, seldom realized that every boat carried along a stream or by a tide is an instance of falling water doing mechanical work, and such work is done at an efficiency of very nearly 100 per cent. I suppose that is the reason why floating down stream is so pleasant. Water-wheels of various types were in use in ancient civilizations, and the distribution of water for irrigation probably preceded the great works of antiquity for water supply in towns. I have already alluded to the water-wheels at London Bridge employed for distributing water in London up to as recently as 100 years ago. During the last century water-wheels gradually became less and less in evidence, and turbines took their place as being more readily adapted to circumstances. But after the early part of the century water power was itself at a discount, and more attention was given to the development of steam pumping-engines.

You are, no doubt, all aware that it was the necessity of pumping water out of the mines, more particularly in Cornwall, that led to the invention of what is known as the Cornish type of engine and the Cornish boiler. Even in 1827, these types had reached a very high degree of efficiency, and improvements since made have been mainly the result of improved manufacture, permitting the employment of much higher pressures of steam and less costly designs of engines of a self-contained character. I am here referring to high-lift pumps. For low lifts, during the latter half of the 19th century, centrifugal pumps were generally adopted.

On the question of pumping water, I ought not to pass unnoticed the great development that has been taking place since Hawksley's death. It was characteristic of him that he should have adhered so closely in the matter of waterworks pumping machinery to the type that long experience had proved to be efficient and reliable,* but nowadays the waterworks engineer has many alternatives to choose from. Such an installation, for instance, as that of the Humphrey pumps, recently erected at Chingford, would have startled Hawksley, but I have no doubt that any new development presented to him, and clearly proved to have substantial advantages on old methods, would have been adopted by him without hesitation.

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* *See* Fig. 5, Plate 37.

Then there is now the turbine pump, and the air-lift pump. As prime movers, there are the large gas-engine, the Diesel oil-engine, and the high-speed steam-engine and dynamo which the extraordinary improvement in the construction of wheel-gearing has rendered possible as competitors with the comparatively slow-running and direct-acting steam pumping-engines. The latter, when centrifugals were unsuitable, were alone available for waterworks engineers during the greater part of Hawksley's lifetime. The progress made in the 19th century in this particular matter was, after all, not so very great, and one can quite understand Hawksley's point of view.

A good Cornish engine of the period of Thomas Hawksley's first undertaking in Nottingham and an example of a recent engine belonging to the Metropolitan Water Board were shown.*

	CORNISH. Fig. 8.	TRIPLE. Fig. 9.
B.Th.U. per i.h.p. per minute, in the two examples	535	250
B.Th.U. per i.h.p. per minute for ideal engines working between the respective limits of temperature on a Rankine cycle, in the two examples	225	158
Efficiency ratios	0·42	0·63

The earlier engine required 30 lb. of steam per i.h.p.-hour and the later engine about 12 lb. In these examples the later engine required only two-fifths of the steam needed by the earlier engine, while the efficiency ratios were as 3 to 2. The figures are approximate only. The men of one hundred years ago were, in fact, able to get extraordinarily good results, considering the means at their disposal.

Causes of Development in Industries.—Much the greater part of the wonderful mechanical development of the day has not been due to any development in the quality of the men, but to the tools adapted for their use. This suggests a rather seductive line of thought. Take, for instance, the recent startling achievements of aerial flight. But for the discovery of mineral oil and its products, we should still be in the "Icarus" stage of classical times. It is the development of the petrol engine and improvement in materials used in the construction of the aeroplanes that have rendered flight possible. Similar factors have led to the progress of automobiles, of shipping with its steam-turbines and Diesel engines, of railways, of docks, and indeed of nearly every department of industrial and mechanical activity. Electrical development has been the result of the discovery of the convertibility of mechanical into electrical energy, and the reversibility of the dynamo. Science, invention, and manufacture have gone hand in hand, and it is in their continued and progressive co-ordination that the future prosperity of our race seems to be assured. While we may well be proud of the results obtained, and be hopeful for the future, there is no ground whatever for self-laudation at the expense of those who have preceded us. Indeed it is questionable if men of a past age were not our superiors in the essential elements that go to make a great nation. Even if this were the fact, it would still be an encouraging thought that an industrious and energetic population, even if, as Carlyle put it, "mostly fools," can accomplish so much under the present circumstances of the world. But if the men and women of past generations equalled or surpassed in essentials those of the present day, how was it that their progress was relatively so slow? The greater pace of development in recent times is commonly supposed to have been due to the combined power of the steam-engine, coal mines, and, latterly, to electricity and oil: but are these things really at the root of the matter? Their influence has been immense, and it is a trite saying that every step upward gives a platform from which to take another spring; but how often has the platform been knocked away through ignorance and folly? Peace and the accumulation of wealth are essential to industrial progress. Wise government and stable finance are as necessary as science, invention, and manufacture for the development of the mechanical arts. For instance, there is reason to believe, from what we know of the scientific and industrial achievements of the Egyptians,* that the remarkable development of science and engineering which has characterized the last 150 years, would have been anticipated by many centuries if it had not been for the waste of war and loss of wealth incurred in gratifying the ambition and the luxurious tastes of the rulers. The real difference between those ages and ours is not the superior ability of the men of our own day, but is the outcome of the gradual growth of the social spirit, and the comparative freedom secured for the exercise of whatever talents the population may possess.

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* Figs. 8 and 9, Plate 38.

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* For instance, the Screw of Archimedes, Fig. 10 (page 1231).

General Considerations governing the use of Water as a Mechanical Agent.—The ultimate source of all the natural water power in the world is the heat of the sun, which is continually and silently evaporating the water on the surface of the earth. The vapour rising in the atmosphere is condensed and descends again in the form of rain, both on the highlands and lowlands, and in the oceans. There is therefore a perennial source of mechanical power in the fall of water from a higher to a lower level, and it is the power of falling water which is in evidence in every system of water supply and distribution, even though the primary object of such works has been usually that of domestic consumption rather than the use of water as a mechanical agent.

Gravitation and Pumping.—In what are known as gravitation supplies, it is obvious that the reservoirs from which such supplies are given must be at such an elevation above the place of consumption as will give a sufficient pressure for the purposes of the consumer. The Waterworks Engineer, in considering the requirements of the consumer, would take into account the desirability of supplying water to the tops of the highest buildings at the greatest elevation of the district supplied, the provision of sufficient pressure for the flushing of drains, for the extinction of fires, and the manufacturing and non-domestic uses for which a water supply might be needed. Now it will be generally found that, except in the neighbourhood of mountain ranges, there are insurmountable difficulties in the way of placing gravitation reservoirs at such an elevation as will provide the power required even to give such domestic supplies, the whole force available being even insufficient to overcome the losses in the conduits and pipes and to give the necessary pressure at the consumer's taps for his domestic use, let alone any use that might possibly be made of the water pressure for mechanical purposes. Further, the purity of water for domestic consumption being a paramount consideration, there is a tendency for the large cities, wherever practicable, to go far afield for their supplies into the nearest mountains. The further they go, the higher must be the elevation of the reservoir, and, notwithstanding the greater height of the fall, the whole, or practically the whole, power of the water is absorbed in its distribution.

Where the conditions are favourable, I suppose every engineer would adopt a gravitation supply, but the number of cases in which this is possible are limited, and in the great majority of waterworks pumping machinery must be installed.

The value of pumping water is not confined to the mere artificial production of the head required for an efficient water service, but it enables the valuable sources of underground water to be tapped. The water from springs and the deep underground natural reservoirs in the various water-bearing strata is not of the same class of purity as the mountain gathering grounds, but, as we all know, is often highly charged with mineral matter. Such waters are probably quite as wholesome for general consumption as the softer upland waters, and are freer from organic impurities. When water is pumped, it is evident that the engineer is free to adopt any pressure that he thinks suitable. He can supply at different pressures to serve different parts of the district, or for different purposes, and in many ways the engineer has a much freer hand than in the case of a gravitation supply.

The power inherent in falling water is in evidence in every system of water distribution for domestic use, also in the construction of docks and canals, and in the numerous manufacturing and industrial purposes for which water pressure is employed. The efficient working of docks is dependent on the tidal flow. The working of canals is largely dependent on the flow of rivers. As in distribution of water for domestic purposes, so in the case of docks and canals, where the natural flow is insufficient in quantity or in elevation, the additional amount or head required can be and is, in many cases, supplemented by pumping.

Drainage Complementary to Water Supply.—The same principles apply in the important matter of drainage. There is the natural drainage of a country due to the fall of water from the highlands to the lowlands, and when Nature is left to itself the whole of the mechanical power inherent in the fall is wasted in grinding up the country, or stored, in forming great lakes, or fens, or swamps. As pumping water for domestic consumption, or for the purpose of irrigation, or of canals, or docks, artificially raises the natural available head of the water in these areas, so in the case of the drainage of the low-lying areas of fens or swamps,* pumping the water may be said to have a similar effect to raising the level of these areas so that water will flow from them. Drainage is complementary to water supply and essential to it. It cannot be ignored, for whatever may be the purposes, mechanical or otherwise, for which the water is used, after use it has not ceased to exist as water, and it must flow away somewhere. There must be suitable provision for the discharge of this flow, and thus a part of the total head or pressure is necessarily wasted.

Pressure Machines and Velocity Machines.†—In most of the applications of water power with which I have hitherto been concerned, it has been the flow or supply of the water itself which has been the main consideration, and the pressure at which such water reached the consumer has been fixed with but little, if any, consideration to the mechanical uses to which the pressure could be applied. In fact, it was not till 1795 that the value of water pressure as a mechanical agent was at all adequately appreciated. In that year Bramah invented the hydraulic press,

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* *See* Fig. 11; also I.Mech.E., Part 3, 1913 (page 788).

† Figs. 12, 13, 14 and 15, and Fig. 17, Plate 38.

FIG. 10.
Archimedes Screw,
250 B.C.
(Ewbank's
Hydraulics, 1847.)

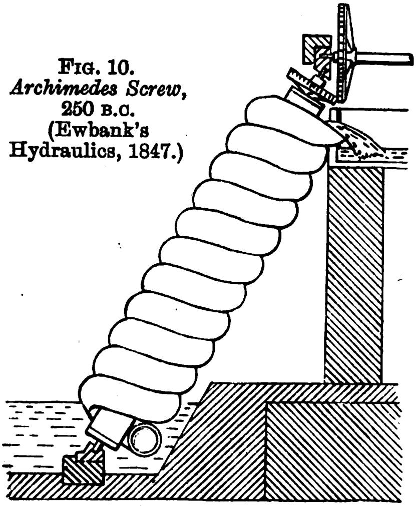


FIG. 11.—*Whip Scoop used in Fen District before* 1862.

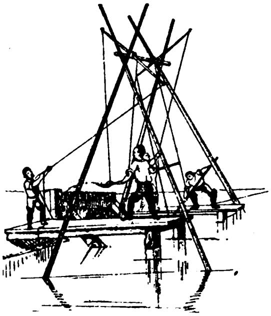


FIG. 12.
Bramah's Press.

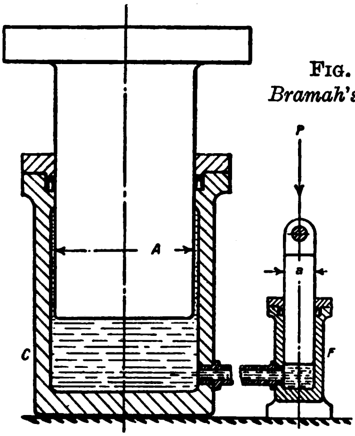


FIG. 13.
Barker's Mill.

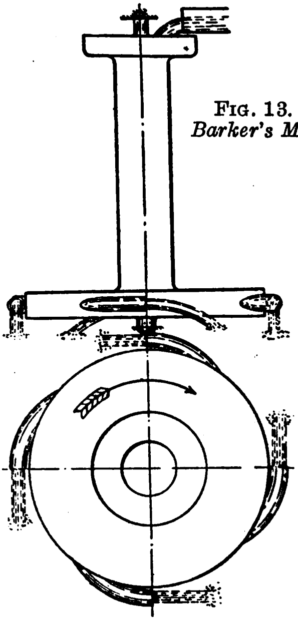


FIG. 14. *Borda Turbine.*

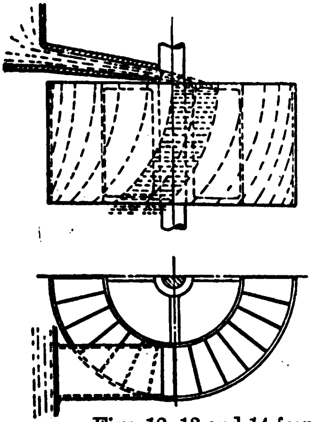
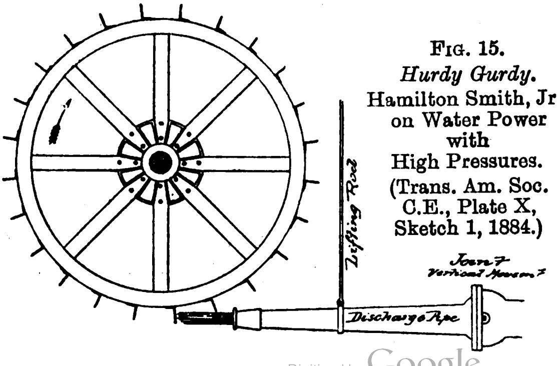


FIG. 15.
Hurdy Gurdy.
Hamilton Smith, Jr.,
on Water Power
with
High Pressures.
(Trans. Am. Soc.
C.E., Plate X,
Sketch 1, 1884.)



Figs. 12, 13 and 14 from "Hydraulics and its applications," Gibson, 1908.

and it was this invention which led to the great advance in the utilization of water pressure during the last century. There have been two great lines of development in recent years. The one initiated by Bramah has been concerned directly with water pressure. The other has had to do with utilizing the kinetic energy of the flow of water. The principles of the hydraulic press are to be found embodied in every hydraulic pressure machine, and as the hydraulic press may be taken as the type of such machines, so the turbine may be taken as the type of a velocity machine. In so far as water-wheels are worked by the flow of water, both the pressure and velocity of falling water are to some extent utilized in their mechanism, but in an overshot wheel it is the mere weight of the water which does the work, and in the old undershot wheel hardly more than the flow of the natural stream is employed. With ordinary water-wheels the limit of head that can be utilized is soon reached, and the largest wheel ever erected—that at the Great Laxey Mine in the Isle of Man—was only 72 feet in diameter and 150 h.p.*

Turbines were really first introduced by Fourneyron about the year 1827. The original idea was to obtain a machine which would work with greater efficiency, and which could be more easily applied in circumstances under which the simple water-wheels had been used. They were accordingly usually driven by the natural streams of water at low heads. A great advance in the direction of utilizing very high falls was made by the invention of impulse turbines of the Girard type, in which the kinetic energy of the flow of water from a nozzle impinging on the wheel was absorbed and utilized. It is rather curious to note here that the improvement made by Poncelet early in the 19th century in undershot water-wheels, which consisted in curving the vanes against the direction of the stream, really converted such wheels into a sort of bastard turbine of the impulse type.

An immense development in the utilization of natural falls of water has been brought about recently by the great improvements effected in turbines, and the improved means of distribution of power through the harnessing of electricity to the service of mankind. The great reservoir works of the past were mainly executed for the purpose of distribution of water for domestic use, and as we have seen, the pressures employed were only those which were suitable for home consumption. At the present day, the field available for the energy and skill of the waterworks engineer is vastly greater, and all over the world great works for the storage of water for power purposes have been established, or are in progress. So far as the reservoirs are concerned, there is no material difference in their construction, whether the water stored is to be used for domestic purposes or for power, but for the former the pipe or conduit line is laid as nearly as possible to the hydraulic gradient between the impounding reservoir and the town or area to be supplied with water, whereas for the latter the object is to obtain the greatest possible fall in the shortest length of pipe line.

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* Fig. 16, Plate 38.

Pipe Lines.—As to water-pipes, it is difficult to realize that cast-iron mains were only introduced about the year 1800. In earlier times stone pipes (i.e. quarried stones with holes made through them and jointed together with stone sleeves) were employed and also wooden pipes or trees bored through and socketed together. I have frequently unearthed both kinds in the London streets. There has been a very interesting recent development in the Western States of America, where built-up wood stave pipes are frequently used for large mains up to 52 inches diameter or more and working under heads up to at least 200 feet.

In carrying out modern water-power works many new problems have had to be solved. Carefully designed and constructed pipe lines are essential to the success of such works. This is what the late Mr. Zodel wrote in the important Paper he read at a recent Summer Meeting of the Institution in Zürich—"The Siagne Power Station (in the South of France) provides a specially interesting and instructive case of high-pressure pipe lines, and has demonstrated in a most drastic manner what the consequences of incorrect design may be. The original pipe line had to be abandoned after a few months' running on account of unsatisfactory working of the plant and an entirely new pipe line had to be built . . . in spite of the fact that the chief dimensions of the pipes were perfectly correct and amply sufficient for the conditions of head and discharge, and moreover not altered in the second pipe line."*

Works at Loch Leven.—As an instance of successful works, I may mention those recently executed for the Aluminium Company at Loch Leven in Scotland. The reservoir has a storage capacity of 20,000 million gallons and the power stored is 30,000 h.p. for 100 days. The pipe lines consist of six steel pipes 39 inches in diameter, from 0·87 to 0·39 of an inch thick, and the anchorages, constructed of concrete, have to resist a pressure of 34 tons at the bends. The maximum head is 935 feet.

Works at Schaffhausen.—A very interesting case is that at Schaffhausen. The fall of the Rhine is employed to drive a number of turbines which, coupled to dynamos, supply electricity to the neighbourhood. While the flow of water is constant the demand for electricity is very irregular, and in order to utilize the principal turbine plant to the fullest extent, supplementary plant has been put down,† which can alternatively be used for pumping water up to a reservoir in the mountains at an elevation of about 500 feet, or for driving a turbine and dynamo by the water in the reservoir to help the peak load. A diagram ‡ shows the actual working of the plant during twenty-four hours. The combined efficiency of the whole plant is 50 per cent.

Works at Chester.—As an example of the use of the flow of a tidal river near its mouth, there are the somewhat unique works just completed at Chester.§ There is a very old weir there, close to the old bridge, which dams up the Dee to something below spring

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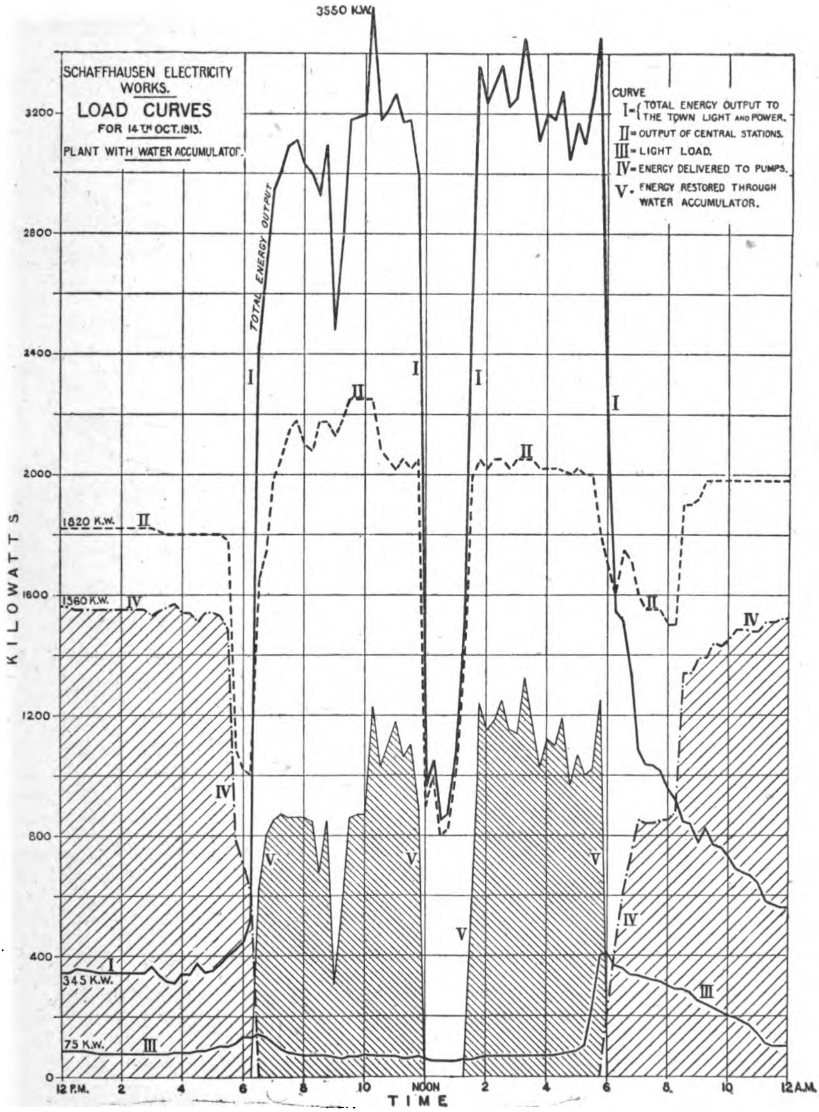
* Figs. 18 and 19, Plate 39. A view of the Main Anchorages at the Power Station, Brusio, Switzerland, is shown in Fig. 20.

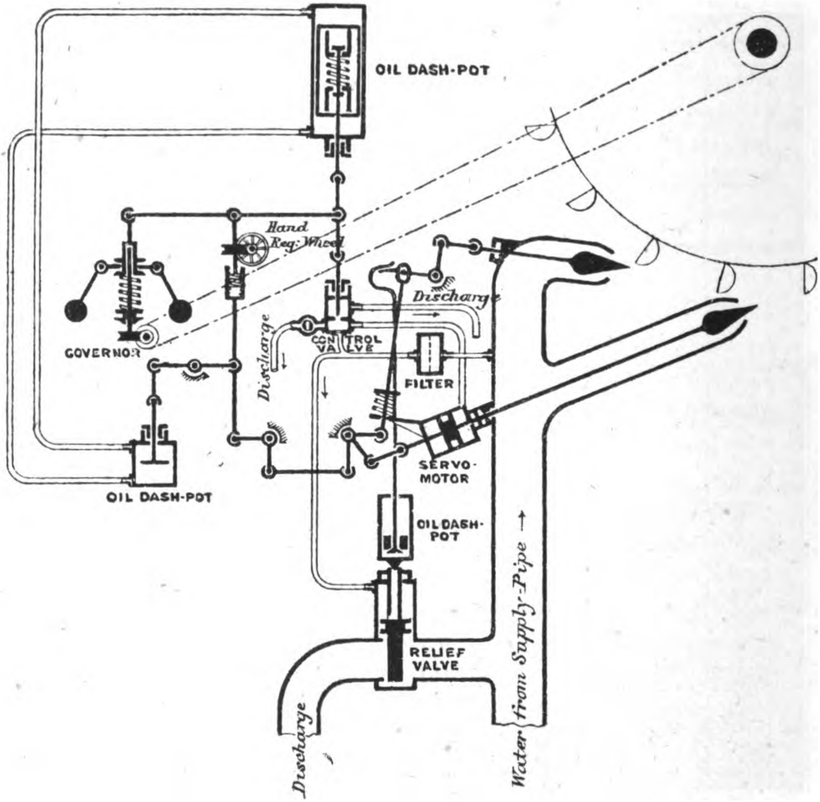
† Fig. 21, Plate 39. ‡ Fig. 22. § Figs. 23 and 24, Plate 40.

FIG. 22.—*Load Curves.* (Dr. Amsler.)



tide level. This weir dates from about the time of William the Conqueror, and the fall has been continually used until recently for working water-wheels for driving a corn mill. This has now been demolished, and a hydro-electric plant has been put down for helping the steam electricity supply of the Corporation. Three Francis turbines have been installed aggregating 1,100 h.p., though the maximum obtainable is not more than 800 h.p., owing to variation in the volume of flow and the head. From the running of the plant during the past few months it is

Fig. 28.—*Diagram of Governing-Gear, Kinlochleven.* (Inst. C.E., 1911.)



expected that the estimated output of 1,250,000 B.O.T. units of electricity per annum will be obtained at a cost of 0·35*d.* per unit. The fall utilized is very similar to that at Old London Bridge, and the power is really obtained through the tidal flow. The turbines run with from 15 inches to 8 feet head.*

Pelton Wheels.—A later development was the Pelton wheel, first brought into actual use in the United States in connection with the big mining industries in the Western States. Pelton wheels are now generally employed for high-pressure work. They will give an efficiency of 85 per cent. The critical velocity of the periphery of the wheel is half the velocity of the jet. Jet turbines possess the great advantage that the power can be reduced with a very small loss of efficiency by simply reducing the size of the jet impinging on the wheel. In many cases, two or three jets are employed on the same wheel at different points, so that the power can be adjusted by diminishing or increasing the number of jets at work without any alteration in the size of the individual jets.

The automatic control of turbines involves many interesting mechanical problems which have been solved in such a manner as to leave little to be desired.†

Bramah's Expectations.—It should be noticed that turbine improvements have had their origin in the desire to utilize to the fullest extent gravitation supplies of water. It is quite different with the line of development of the hydraulic press. Here pumping is generally employed, and the engineer is not restricted in his operations by the limitations imposed by natural falls of water. Bramah appears to have been the first to make a practical machine, and he completely realized the value of his invention and the extensive use to which it could be put. He himself applied it to the hoisting and lowering of goods, as will be seen from a letter written by him in 1802, part of which I will quote :—

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* Figs. 25, 26 and 27, Plate 40.

† *See* Fig. 28; Figs. 29 and 30, Plate 41; also I.Mech.E. 1910 (page 8).

> "I think much might be done in Ireland in the press way if the excellence of the principle was known; I have also now applied it with most surprising effect to every sort of crane for raising and lowering goods in and out of warehouses. So complete is the device that I will engage to erect a steam engine in any part of Dublin, and from it convey motion and power to all the cranes on the quays and elsewhere, by which goods of any weight may be raised at one-third of the usual cost. This I do by the simple communication of a pipe, just the same as I should do to supply each premises with water . . . .
>
> "I believe I shall have all the cranage of the London wet dock warehouses to undertake, and which will be the grandest job perhaps ever done."*

He thus anticipated the development of fifty to sixty years later, though apparently nothing more came of his suggestion at the time. I have already shown an illustration of Bramah's press.

Forging Presses.—I believe one of the largest and certainly the most up-to-date hydraulic presses in existence is that recently erected at Messrs. John Brown and Co.'s Atlas Works, Sheffield.† The press exerts a force of 6,000 tons and the maximum pressure employed is 2½ tons per square inch, equivalent to a head of water of about 13,000 feet. The ordinary accumulator pressure is about 1,700 lb. per square inch, the higher pressure of 2½ tons being obtained by means of steam intensifiers. There are two sets of pumping engines delivering 150 gallons per minute at the lower pressure. This compound method of supplying the pressure has proved very economical.

Though the great value of forging presses has only become generally recognized in recent years, so long ago as in 1869, about the time when Whitworth introduced his principle of compressing steel ingots to secure soundness, the late Mr. Manasseh Gledhill erected a forging press at Whitworth's Manchester Works. This press exerted a force of 800 tons and the pressure employed was 5,200 lb. on the square inch.* Hydraulic presses now form a part of every well-equipped steel works. It is owing to the development of such presses that the large masses of steel now required for big guns, shafts, and turbine forgings have been satisfactorily produced.

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* Proc., Inst. C.E., 1877, vol. xlix, page 30.

† Fig. 32, Plate 42.

Cotton and Bale Pressing.—For packing also there has been enormous development during the last 100 years. Cotton pressing has been brought to a state of perfection which is really wonderful: in India alone † there are at least 1,000 cotton presses at work, and the baling of manufactured goods in Manchester and elsewhere is a great business. It is interesting to consider how the development of one line of business reacts upon another. As the demand for freight extends, greater efforts are made to reduce the bulk of goods. The greater the shipping trade the greater is the demand for appliances for the handling of cargoes and the saving of time in their loading and discharge. It certainly seems surprising that the great idea of Bramah in this direction should have lain dormant so long.

Energy available in ordinary Water Mains.—The water power in the mains of the big waterworks with which Thomas Hawksley had so much to do, was certainly, from time to time, considered, and many water engines were designed,‡ and some actually used, but the possibilities in this direction were not very large, for as we have seen, in the great majority of waterworks, there is but little surplus power available. If one takes a standard of 200 feet head as the available pressure in ordinary waterworks mains, and an efficiency of 75 per cent. is assumed for the engine, the consumption of water would be 1,300 gallons per effective h.p. hour—which would be as much as the domestic use of water per day of about fifty persons. It is evident that only a limited use could be made of water power from such a source, and that it could only be effectively employed for intermittent use, such as for lifts and cranes, for organ blowing, or for presses of small power used a few times a day. It was for such purposes in fact that the water power in the water mains was principally employed.

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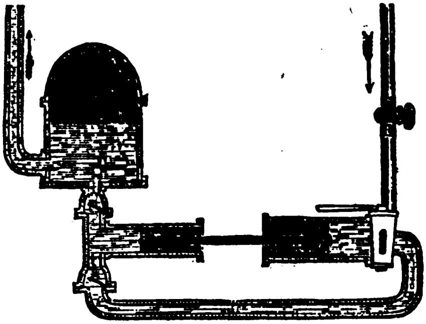
* Figs. 33 and 34, Plate 42.

† Fig. 35, Plate 42.

‡ Fig. 17, Plate 38; and Fig. 36 (page 1240).

Lord Armstrong's Inventions.—It is of interest to note that the great development of the last sixty years, due to the late Lord Armstrong, was started (after his preliminary experiments with a water-pressure engine) by the erection of a hydraulic crane on the quay at Newcastle, worked from the pressure of the water mains in that city. This was, of course, exactly the idea of Bramah on which he had worked more than forty years before and about which he wrote in the letter I have quoted, though it is clear that Armstrong's invention was independent of Bramah's work.

FIG. 36.—*Pressure Engine from Belidor*, A.D. 1739.
(Ewbank's Hydraulics, 1847.)



The soil was not ripe for Bramah's cultivation, and the experiment of Armstrong at Newcastle served to show the very serious limitations of the then existing conditions of water supply to further the objects in view. Armstrong was soon convinced that if anything big was to be made of his invention it would be necessary to consider the problem *sui generis*, and to abandon the notion of utilizing ordinary water mains. However, it would not be quite accurate to say that this was the immediate result of the installation of the Newcastle crane, because a complete system of hydraulic cranes worked from the ordinary water mains was, in fact, established in one of the warehouses of the Liverpool Docks and at the North Eastern goods depôt at Newcastle. Then came the large development at Grimsby, and here for the first time an independent water supply system was laid down solely for the distribution of water power for the working of the mechanical appliances at the docks. This was a great advance, but the crux of the problem had not even then been realized.

If water as a mechanical agent was to become a really important factor in industrial work, it was essential that there should be an entire severance from the already existing system of water supply, and that everything should be started *de novo* on the footing of a working pressure largely in excess of anything ever before attempted in the way of distribution. Ultimately Armstrong arrived at the conclusion that for the purpose of docks, railways and contingent works, such as wharves and warehouses, a pressure of 700 lb. per square inch was what was required. The Tank Towers at Grimsby had been built 200 feet high according to the recognized standard of waterworks practice. It seemed preposterous then to contemplate the erection of towers 1,500 feet or more high, and accordingly the equivalent of such towers was sought for. The invention of the Armstrong accumulator resulted in the year 1851. The accumulator is a reversed hydraulic press. Instead of water power making a bale of goods, a mass of material of sufficient weight gives the water pressure. So the problem was solved, and an entirely new system of water distribution came into being.

The hydraulic crane on the quay at Newcastle was erected in 1846 and the Grimsby plant a few years later. During the following half century the Armstrong system had an uninterrupted career of prosperity and was generally considered absolutely unrivalled for the service of railways and docks. Hydraulic power was eventually applied to the turning of turrets and guns, to the steering gear of ships, and particularly to the working of the plant required for the manufacture of Bessemer steel, mainly designed by Bessemer himself.

Recent Developments in London, Manchester, etc.—My own experience of Armstrong's work dates from the year 1870, and it was at this period that attempts were first made to establish high-pressure waterworks exclusively for the general supply of hydraulic power in towns on the accumulator system. The pioneer undertaking was started at Hull, followed some years later by the great works of the kind in London, started in 1882, and afterwards in Liverpool, Manchester, Glasgow, Birmingham and other places. These works have been particularly successful in London and Manchester. In London, where more than 7,000 machines are worked from 175 miles of mains, the pressure adopted was Armstrong's standard of 700 lb. per square inch at the consumer's premises at the highest point in the system, and provision was made for a maximum pressure of 850 lb. per square inch at the pumping stations. At Manchester, the pressure adopted was 1,120 lb. per square inch in order the better to supply the requirements of the great packing-houses. The question of pressure is one of great importance. In London it has already been found necessary to introduce feeder-mains working at 1,000 lb. per square inch. Owing to the improved methods of manufacturing steel pipes, there is now considerable economy in using the high velocity of flow of 10 feet per second in the feeder-mains notwithstanding the greater distribution losses involved. There is a large use of hydraulic power for riveting and machine tools in boiler works, with the development of which the name of the late R. H. Tweddell will always be associated. He adopted for such work 1,500 lb. per square inch, and there was no difficulty in the distribution of this pressure. With the existing manufacturing facilities, there is no reason why a pressure of, at any rate, 1 ton per square inch should not be used for general distribution.

The New Factor of Electricity.—It is almost impossible to deal with the subject of water as a mechanical agent without having electricity in one's mind, because anyone who has had to do with power distribution in any form must necessarily, nowadays, consider the new factor of the dynamic application of electricity which has done so much for the world during the last quarter of a century. What water really is and what electricity really is in its ultimate analysis we do not know. They may be both vortices of force, or even conceptions of mind. As engineers, we can only deal with them as manifestations of matter, and their respective merits should be considered without bias. It is quite impossible that we can be on the right track if we start with the assumption that there is necessarily a *primâ facie* case for cleaving to one and discarding the other. There are extraordinary similarities between them, for if you consider electricity as if it were water without weight, a conception is obtained which will enable one to some extent to trace and explain analogous phenomena in both materials. Both appear in themselves, from our point of view to-night, as quite inert. With both, in order to obtain mechanical effect, there must be a fall from a higher to a lower plane involving movement of the material. Water falls to the ocean and electricity to its own level. There is a world-wide circulation of both.

Relative advantages of Water and Electricity.—There are, so far as we know at present, no natural sources of electricity which can be directly tapped for use, as is the case with water power, and from a mechanical point of view, the more direct the application of power the better. This is, however, often a counsel of perfection. For instance, it has been found that in order to use the natural falls of water to the best advantage it is essential to convert this water power into electricity, because electricity can be used in such an infinite variety of ways, and because of the unrivalled facilities it possesses for distribution. But while there can be no question as to the great value of the hydro-electric works, now being established all over the world, it is quite another thing to adopt electricity as the mechanical agent in circumstances where other sources of power are mechanically simpler and better. While it may be taken as established that the turbine wheel and dynamo are the simplest and best means of utilizing natural falls of water, and thus obtaining electric current, so also it is impossible to imagine a simpler or more effective machine than a hydraulic press and its derivatives for certain purposes. In such cases it would seem to be desirable to convert electricity back again to water power if direct hydraulic power is not available. Whether one power or the other should be used for any particular purpose should depend on the relative merits of the machines that have to be adopted. The practical monopoly which water-pressure machines maintained for so many years in the lifting and hauling appliances of docks and railways had, I think, an unfortunate effect in restricting improvement in detail, and the efficiency of such apparatus is, as a rule, far below that of which the system is capable. The system has also suffered from the defects of its qualities, for it is a fact that water-power machines will usually do their work somehow or other even when in a very defective condition of maintenance, whereas under similar conditions electrical machines will cease working altogether. Users of water power have often been content with plant which has been unnecessarily costly to work because it has been found reliable and safe.*

Power in Rainfall.—On a review of the whole subject, it appears that water power is likely to become increasingly important. It is perennial in its source. As a mechanical agent, it has numerous ramifications which are constantly extending, and its direct application to industry offers a large field for the exercise of the talents of the inventor and the engineer.

The rainfall at 25 inches per annum is 1,600,000 tons of water per square mile in the year, and if it is assumed that the water actually falls a distance of 500 feet, the rainfall alone is sufficient to give over 100 h.p. per square mile continuing throughout the year. In the United Kingdom and Ireland there are 121,000 square miles and a population of 45 millions. At 25 gallons per head per day, one square mile will supply 40,000 persons, so that the total population requires for domestic use less than 1 per cent. of the rainfall. Further, allowing one-third of the total yield for vegetation and evaporation, the net water power remaining for industrial use, if it could be stored, would give 70,000 millions h.p. hours in the year. The average user would be for about 2,000 hours in the year, and on this basis there would be available 35 million h.p. These figures give some idea of the enormous energy of rain in the world at large and the possibilities of the future.

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* Fig. 31, Plate 41.

Works for the storage and distribution of water power are now claiming almost as much attention as the storage and distribution of water for domestic consumption. The study of hydraulics has always been fascinating as a branch of science. Hydraulic laboratories are an essential feature of every well-equipped engineering college. The subject offers many opportunities for experiment and research, and this Lecture will have served its purpose if, to any extent, I have succeeded in stimulating thought and interest in Water as a Mechanical Agent.

I desire to acknowledge the valuable assistance I have received in the preparation of this Lecture from Mr. Charles Hawksley; Dr. W. Cawthorne Unwin, F.R.S.; Mr. Percy G. B. Westmacott and Mr. Robert Matthews of Messrs. Armstrong, Whitworth and Co.; Mr. H. F. Rutter of the Metropolitan Water Board; Mr. W. H. Ellis of Messrs. John Brown and Co.; Mr. H. Zoelly of Messrs. Escher Wyss and Co.; Professor W. R. Eckart, Jun., U.S.A.; Dr. Alfred Amsler, of Schaffhausen; Mr. William Smethurst, of Manchester; Mr. S. E. Britton, the Electrical Engineer of the Chester Corporation, and Mr. James Gordon, the Contractor for the Works; and from the Secretary and Staff of the Institution.

The Lecture is illustrated by Plates 37 to 42 and 11 Figs. in the letterpress, and is accompanied by an Appendix.

APPENDIX.

The Lecture was repeated in Birmingham, Leeds, Liverpool and Nottingham, and at each of those repetitions particulars of Thomas Hawksley's work of special interest to the locality were alluded to.

BIRIMNGHAM.

Mr. Hawksley had a long and intimate association with the City of Birmingham, extending over 40 years. He acted as adviser to the Birmingham Waterworks Company from the year 1854 until the transfer of the Undertaking to the Corporation in 1875. He was consulted at various times between 1863 and 1875 by the two gas companies which supplied the City and vicinity, and sat as one of the Arbitrators in 1877–8 to settle matters connected with the transfer of the Undertakings to the Corporation of Birmingham. He also advised the Corporation from time to time on the Sewage Disposal Works and in part carried them out.

LEEDS.

Mr. Hawksley's professional association with Leeds commenced in 1851, and continued from then until his decease 42 years later. An Act of Parliament was obtained in 1852 for the transfer of the Undertaking of the Leeds Waterworks Company to the Corporation of Leeds, and authorizing new works necessary to obtain a supply from the River Wharfe, and in 1854 Mr. Hawksley was appointed engineer for carrying them out. In 1867 the Corporation obtained powers to construct further works in the Washburn Valley under the advice of Mr. Hawksley and Mr. Filliter, who were joint engineers for the execution.

LIVERPOOL.

Mr. Hawksley's connection with Liverpool extended over a long series of years from about the year 1847, when the Corporation obtained, under his advice, power to purchase the existing water undertaking, and to construct the Rivington works mentioned in the Lecture.

NOTTINGHAM.

As Mr. Hawksley's native town, his intimate professional association with the place is dealt with at some length in the Lecture, but one of the great personal triumphs of his career at Nottingham was the successful and at first almost unaided promotion of the Nottingham Enclosure Act, by which 900 acres of common land, known as Mapperly Plain and Nottingham Forest, were rescued from the mismanagement of the Freemen. This legislation has proved of inestimable advantage to the prosperity and health of the whole community of Nottingham.

The Institution of Mechanical Engineers.

PROCEEDINGS.

19th December 1913.

An Ordinary General Meeting was held at the Institution on Friday, 19th December 1913, at Eight o'clock p.m.; Sir H. Frederick Donaldson, K.C.B., *President*, in the Chair.

The Minutes of the two previous Meetings were read and confirmed.

The President announced that the Ballot Lists for the election of New Members had been opened by a Committee appointed by the Council, and that the following fifty-nine candidates were found to be duly elected:—

MEMBERS.

Broadbent, Ernest Edgar,	Sydney.
Drewitt, George Duncan,	Cairo.
Glaze, Charles William Livock,	London.
Heap, Arthur Cecil,	London.
Kellow, Moses,	Penrhyndeudraeth.
McVicar, Alexander,	Wellington, N.Z.
Quennell, William Alec, Capt. A.O.D.,	Quetta.
Reed, Henry Ashman,	Manchester

ASSOCIATE MEMBERS.

Anderson, John Herbertson,	Wellington, N.Z.
Badger, Saxon Alfred,	Rotherham.

Beeching, Edmund,	Great Yarmouth.
Bishop, Sydney Montague,	Monte Video.
Blythe, Edward,	Hull.
Chapman, James Fraser,	Halifax.
Cox, William Tom,	Colombo.
Davies, Francis David,	Maceió.
Dunbar, James,	Christchurch, N.Z.
Gillett, Thomas,	Bookham, Surrey.
Green, Thomas,	Runcorn.
Grierson, Ronald,	London.
Griffiths, David Nathaniel,	Northwich.
Griffiths, Royston Swire,	Cardiff.
Hallowell, William,	Manchester.
Hamilton, Frederick Broadhurst,	London.
Hargreaves, William,	Manchester.
Hawes, John Walter Henry,	London.
Homewood, George,	London.
Howie, Harold Aislabie,	Sheffield.
Ingouville, Peter,	Monte Video.
Jinasena, Colombepatabendege,	Colombo.
Macaulay, Maxwell Stanley,	Mansourah.
Manico, Edward Leslie,	Sukkur.
Moss, Henry,	London.
Ord, John Thompson,	Iquique.
Parsons, Henry Arthur,	Mendoza.
Pell, Henry William Leach,	Maldon, Essex.
Ridgway, Albert Edward Augustus,	Kuala Lumpur.
Riehn, John Frederik,	Oakengates.
Rodda, Henry Colenso,	Swindon.
Simpson, Frederick Dudley,	Birmingham.
Stewart, Charles Edward,	Dorchester.
Thompson, Harold Stanley Victor,	London.
Thompson, Joseph,	Tokyo.
Weekes, Barnett Norman,	Liverpool.
Wilkie, George Matthew,	Tampico, Mexico.

GRADUATES.

Gurnhill, John Byron,	Gainsborough.
Henderson, Charles Graham,	London.
Inglefield, Aubrey Fitzmaurice, Lieut. R.N.	Portsmouth.
Jones, Charles Harold,	Wolverhampton.
Ludlow, Wilfrid Arthur Charles,	Portsmouth.
Nakai, Udham Singh,	Glasgow.
Parsons, Cyril Gordon,	Bristol.
Partridge, Charles Frederick,	Old Hill, Staffs.
Prothero, Edwin George,	Birmingham.
Rogers, Leslie Norris,	Birmingham.
Skinner, Alec Joseph,	Woolwich.
Smith, Clarence Herbert,	Manchester.
Stackard, Stephen Frank Cyril,	Cambridge.
Trigle, Sidney Edward,	Wakefield.

The **President** announced that the following eight Transferences had been made by the Council:—

Associate Members to Members.

Barge, Henry Lowthian,	London.
Baynes, Frederick Walter,	East London, C.C.
Clements, Fred,	Chesterfield.
Goodyear, William,	Gravesend.
Graham, James,	Manchester.
Mallinson, Arthur Benjamin,	Manchester.
Nasmith, John,	Birmingham.
Newton, Edgar Venables,	London.

The following Paper was read and discussed :—

"Mechanical Engineering Aspects of Road Construction"; by Colonel R. E. B. Crompton, C.B., R.E., *Member*, of London.

The Meeting terminated at a Quarter past Ten o'clock. The attendance was 100 Members and 73 Visitors.

MECHANICAL ENGINEERING ASPECTS OF ROAD CONSTRUCTION.

BY COLONEL R. E. B. CROMPTON, C.B., R.E., *Member*, OF LONDON.

The author wishes to lay before the members certain interesting questions arising out of the recent development of Road Locomotion. He believes the time has come when this development and the problems it involves must now be jointly studied, not only by the vehicle designers who are mechanical engineers, but by that branch of mechanical engineers who are the modern road constructors, and as road surfacing, on account of its highly scientific nature, requires further development of constructing machinery. In his writings and discussions before this and kindred Institutions, he has many times called attention to the importance of dealing with road transport as a whole: that the vehicle and the road on which it runs should be treated as a railway with its rolling stock, the two being evidently interdependent.

The development of road vehicle design is already well advanced. The science of preparing the road surfaces to suit these vehicles is comparatively new and requires careful attention. From the point of view of the design of the vehicle, the author is able to look back with some satisfaction to the fulfilment of his often-repeated forecasts of the eventual success of road locomotion. He read his first Paper* before this Institution in 1879 at the close of what was then the first practical large-scale experimental development of road locomotion. The successful work of the Indian Government Steam Train described in that Paper was remarkable, and he hopes that those who are interested will look up the Proceedings and note how much useful work had been done nearly forty years ago, and which for various reasons did not bear fruit for many years following. Fig. 1, Plate 43, shows the Indian engine photographed by the author, and fully illustrated in the Proceedings, 1879, Plates 65–68.

Then came the valuable work done by the French engineers, which advanced self-propelled vehicles so much that in his Address as President of the Mechanical Science Section of the British Association in 1901, the author was able to note that already there was great development in the use of the pleasure motor-car, and this was certain to lead to the extended use of mechanically-propelled motor-omnibuses and motor-wagons which would be likely to have a revolutionary effect on the transport of goods, of passengers in or near our large business centres, and that suburban railways and tramways would find that they had before them a formidable rival in the new methods of locomotion. He then quoted a prophecy by the novelist Mr. Wells, which is worth requoting:—

> "That at no distant date much of the passenger traffic would be carried on special roads in motor-cars; that the advantage of carrying your family and loading up your belongings at your own door in your own or in a hired car and transporting them without any change or handling of your baggage right up to the point where your journey ends, would be so great that, even for comparatively long journeys, travellers would prefer it to the railways which would eventually be relegated to carrying minerals or heavy goods."

Mr. Wells' predictions are already justified, and there is no doubt that the reason he gave was a chief cause of the recent developments.

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* "The Working of Traction Engines in India." Proceedings, I.Mech.E., 1879, page 494.

Returning to the progress in vehicle design, his first Paper to this Institution recorded the advance that had been made during the ten years immediately following Aveling's first exhibition of a practical traction engine at the Royal Agricultural Society's Show at Leeds in 1861, up to the time when Messrs. Ransomes built to R. W. Thomson's designs the Indian road engines described in his Paper. At the time that Paper was read, steam was the only driving power available, so that the road locomotives with their boilers and their supply of fuel and water were necessarily heavy.

During this period of development of traction-engine design the chief features which characterized them became so far fixed and standardized, that the traction-engine of to-day has been but little altered from that of 1871. For the reasons above given, the engines were necessarily heavy, and as their hauling power depended so largely on the weight on the driving wheels, it was not until Thomson, in 1868, fitted solid rubber tyres to the driving wheels of the modified road locomotives, which he called "Road Steamers," that he found that as the adhesion on which the hauling power of a road locomotive depends is so much greater with rubber tyres than with the smooth iron tyre of the traction engine, he was able to reduce the weight of his road-steamers to one-half that of the traction-engines then in use. It may thus be said that Thomson, by the invention of the rubber tyre, both in its solid as well as in its pneumatic form, may rightly claim to be the pioneer of the modern commercial road vehicle, as he was practically the first to design and construct road locomotives with small tare weight in proportion to the paying load hauled by them.

The author on page 501 of his Paper in 1879 showed that one of his Indian engines, weighing 8½ tons, or, including the weight of a separate tender loaded with fuel and water, 12 tons 14 cwt., drew behind it a train weighing 64 tons 6 cwt. containing a net paying load of 42 tons; so it will be seen that at that remote date, by utilizing Thomson's ideas and discoveries, the author had succeeded in raising the weight of the paying load up to 55 per cent. of the total moving load. As such good results were obtained nearly forty years ago, the present generation of engineers may wonder why so little further progress in road locomotion was made up to the year 1895. It is difficult for us, looking back, to realize how that, in spite of the fine performances obtained in India with the Indian engines, here in England everyone—road authority as well as the general public—appeared to combine to oppose the development of road locomotion, especially that designed to run at a speed sufficient to make it pay as a commercial proposition. At any rate, previous to the development in France of the internal-combustion engine as the motive power of the road locomotive, the weight of fuel and water which had to be carried for the steam-engine entailed such small radius of action that this, when added to the restrictions by legislation, was sufficient to confine the benefits of road locomotion, as it then existed, to farmers for their self-moving threshing or ploughing machinery, and to the few who used traction-engines for transporting heavy weights.

The adoption of the internal-combustion engine by Panhard, De Dion, Benz and others gave such an impulse to road-locomotive design, that constructors were able to lighten their vehicles and to avail themselves of all the recently developed knowledge in the use of high-grade steel tubing or framing used by the bicycle constructors, and at the same time and from the same source they had learnt how the vibrations encountered at high speeds could be successfully dealt with by using rubber tyres, either in their solid form or in the latest development of the pneumatic tyre. It will be seen how this combination of circumstances favoured and facilitated their work, and caused a rapid improvement in the pleasure vehicle, which was quickly followed by the commercial vehicle.

Sir David Salomons and a circle of his friends agitated for, and obtained, the removal in this country of the speed restrictions imposed by the absurd Act, commonly known as the "Red Flag Act," which limited the speed of self-propelled vehicles to the walking-pace of a man. Once the legislative restrictions were removed, the advantages of road locomotion began to be rapidly realized, and it was not long before some of the problems entailed by the increased speed demanded the attention of designers. As already mentioned, the almost universal adoption of the rubber tyre and the pneumatic tyre for the lighter class of vehicles minimized the difficulties experienced from road shock and vibration, but with the heavier commercial vehicles the case was otherwise.

Up to this time, traction-engine speeds had been so low that it had prevented them from competing, even on short journeys, with transport by railway. Moreover, the full loads necessary to enable traction-engines to pay their way were against the advantages of door-to-door delivery; but it was soon evident that there would be a great opening for smaller loads carried at higher speeds, especially for the delivery of perishable goods or for carrying such goods as require careful packing to enable them to stand the frequent handling or trans-shipment by rail; direct transport by road enables wagons to load these goods at the dockside at London or at any port and to deliver them direct into the warehouses of the retailer at any points within a radius of 100 miles. Such distribution from a port or manufacturing centre is found in practice to occupy only about one-third of the time ordinarily occupied by railway transport, on account of the double handling being avoided both at the loading end and the distributing end. Again, for goods in smaller consignments, it is a great advantage for manufacturing and carrying firms to be able to use motor-vehicles which can run up to a speed of 20 miles an hour, and so deliver goods up to a radius of 50 miles within a few hours of the order being received. At the outset, designers used a modification of the pleasure vehicle for the lighter class of commercial vans. They commenced by strengthening some of the parts and by altering the ratio of gearing, but it was soon seen that the shocks communicated to the wheels and unsprung parts of the vehicles were imperfectly understood. This imperfect design was followed by heavy repair bills which retarded their further introduction and discouraged their use.

The efforts of designers were then directed to reducing these repair bills by careful study of the stresses introduced by the road shocks, and by increasing the strength of the parts which suffered from them; and by good design and the use of high-class materials they were able to do this without increasing the tare weight materially. Much of the improvement in vehicle design related to changes in the arrangements of gearing, to the introduction of the worm drive for the bevel drive, and in the lighter class of vehicles by the substitution of the live-axle drive for the chain drive which was first employed for all vehicles, and is still employed for the heaviest class. Attention was paid to the design and arrangement of the springs, of shock-absorbers, and of supplementary springs to control the smaller and more rapid vibrations. This class of improvement was quickly followed by such considerable reductions in the cost of maintenance, that, as soon as this became evident, the demand for the vehicles increased. Their use extended so rapidly that already we have reached the partial verification of Mr. Wells' words. Apart from the immense number of long-distance passenger journeys performed by private or hired motor-cars, not only for pleasure, touring, or relaxation, the privately-owned motor-vehicle is rapidly ousting the horse-drawn vehicle for private use. On the commercial side, it is found that door-to-door delivery of goods has so influenced the great business houses in our large towns that they are nearly all owners of fleets of motor-wagons, and that a considerable portion of their output is distributed by this means.

There are in London nearly 3,000 motor-omnibuses dealing with a passenger traffic which is still rapidly increasing and which has been created solely by the speed facilities, the regularity of service, and the increased comfort of the passengers. The development of this class of traffic has already gone far beyond that hoped for and indicated in the author's Address at Glasgow. Already the saving of time from the well-organized motor services has added nearly 10 per cent. to the useful lives of a large proportion of the passengers who use the motor-omnibuses, or who make short journeys into the surrounding suburbs or country. The statistics of road traffic, prepared for the Road Board during the last three years, show that many roads previously deserted by all but local or farmers' traffic, now carry quite a large fraction of the passenger traffic, and of the tonnage of goods previously carried by the railways.

Deformation of Road Surface.—The effect of this new traffic on the roads began to attract attention some years ago. The increasing number of the lighter vehicles and their higher speed produced the dust nuisance. As heavy vehicles were gradually introduced, it was found that they caused extensive deformation of the road surfaces. At the outset the cry was raised that as the increased wear and tear of the roads was caused by the introduction of motor-vehicles, that they and they only should be blamed for the damage of the road, and the Road Authorities demanded that all motor-vehicles should be taxed in order to provide funds for road maintenance. As is known, in the end a tax has been levied on mechanical road locomotion in the form of a licence tax on the vehicles themselves and a petrol tax on the fuel they consume.

Formation of Road Board.—The Road Board was formed to administer grants-in-aid towards road improvements. It is a common mistake to suppose that the funds raised from the vehicle and petrol taxes can be applied to the maintenance of the roads. The Act provides that the grants-in-aid must be applied to improving the methods of construction to enable the roads to resist better the special deformation or wear caused by the new form of traffic.

The author, in his position as consulting engineer to that Board, has had considerable opportunity of noting and studying the whole question of the deterioration of road surfaces, as far as it appears to be due to modern traffic, and lays some of the results of these investigations before the Institution. Road surveyors and others, when discussing the effect of the new traffic on roads, are accustomed to talk of the unevenness of the surface of a worn-out road as if it were actually caused by surface wear, that is by the actual removal of the road material by the rolling of the wheels or impact of the horses' feet from parts of the surface so as to wear down the depressions or low places; but although this was partly true when water was used as the binding material for macadam roads, the mud being scraped away in the winter, or the dust blown off the road in the summer, this actual removal of material from the surface almost entirely ceased after the roads had been tarred or rendered waterproof, so that the deformation of the road surface which continues to show itself wherever traffic is heavy must be put down to other causes.

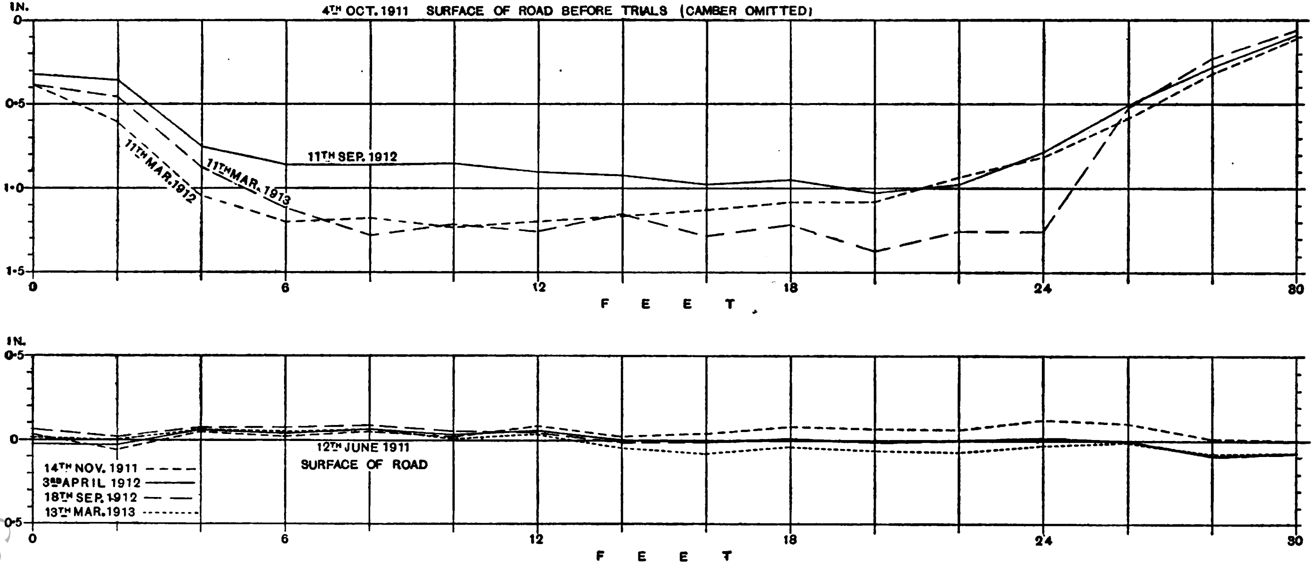
Trials of Road Surfacing Material.—Soon after the formation of the Road Board, the author was engaged in preparing specifications for a number of trial lengths of road-surfacing material to be tested in competition on the main Folkestone Road at Sidcup in Kent, on the London and Kingston Road in the Borough of Wandsworth, and within London itself on certain streets in the Borough of Fulham. In a few cases these trial lengths were carried out by the direct labour of the county or borough councils, and in other cases by competing firms who were thus able to demonstrate their new systems of construction. In order to compare the life or durability of these road surfaces, they were laid down on one road so that as far as possible they could be subjected to identically the same amount and character of wheeled traffic. The author was called upon to measure, and record the rate at which these surfaces were lowered by wear; for this purpose he adopted means that had been previously used in Liverpool by Mr. J. A. Brodie, City Engineer, one of these being by a special form of straight-edge, resting on datum points at the two sides, and in the centre of the carriage-way, and the other suitable for wider roads consisting of a stretched wire strained to a fixed catenary by a weight, this wire being supported on crutches resting on datum points fixed in the footways. Fig. 2, Plate 43, shows the method of taking these measurements with the strained wire, which were made when the roads were freshly put down, and were repeated at regular intervals, at first every month, and afterwards every six months; and Fig. 3 are graphs plotted from the measurements taken by this method.

It was expected that the surfaces would be gradually lowered

Fig. 3.—*Alterations in Cross Contours of Two Carriage-ways between London and Kingston, plotted in each case from the first diagram represented as a straight line.*

Taken with the Apparatus shown in Fig. 2, Plate 43.

These Diagrams taken at half-yearly intervals show irregular variation of contour.



Material in upper carriage-way, Guernsey granite coated with a special bituminous composition and spread in two layers. First layer graded from 2¼-inch down to ¼-inch; second layer graded from ⅜-inch topping. Surface finished with fine chippings. Material heated, mixed, and cooled on site 14 days before use; spread and rolled hot. Consolidated to 3 inches.

in the first instance by some compression, or consolidation of the material, and afterwards by real wearing of the surface under the attrition of the wheels, but it was soon found that the readings taken across the carriage-way between the datum points exhibited curious and unexpected results. As it was evident that the wear would be irregular, it was thought that by taking readings across the carriage-way a foot apart, and adding them up, the mean thus obtained would give the real rate of lowering of the surface; but it soon became evident that although in most of the cross contour the level was lowered, in other parts the surface had actually risen. These measurements being considered doubtful were repeated, and the first measurements confirmed. In following out this matter the author found that this occasional raising of the surface immediately under the cross-contour line of measurement was due to the fact that the point coincided with the crest of a wave which had been formed; because, when a straight-edge was laid in the direction of the traffic at right angles to the cross-contour line, it soon became evident that the lowering of the surface was not due to wear but chiefly to "deformation," that there was really a transfer of the road material in the direction in which the traffic was rolling in some cases from a point underneath the wire to a point further down the road, but that whenever a rise of the surface was indicated immediately under the wire this was due to the contour measurement happening at this point to be taken across the crest of a wave. These observations, added to many others taken on other roads in various parts of the kingdom, have led the author to reconsider the question of road wear or, as he prefers to call it, of "Road Deformation."

Put briefly, the author believes that the deformation of road surfaces, caused by modern traffic, is due to the rolling action of the wheels at the speeds now employed for self-propelled traffic being no longer true rolling, but more in the nature of a rhythmical percussive action, the wheels striking the ground at regular intervals. This percussive action has always a tendency towards deforming the original flat, or approximately flat, surface into a surface having well-defined waves. This wave deformation can become so intense that it can reach a point when it causes the road to break up, namely, when the crests of the waves become so high and the depressions are so deep that the oscillation or pulsation reacts on the vehicle; the road thus becomes so rough to drive over that it is necessary to re-form the surface.

This tendency towards wave formation had already been often noticed by road surveyors, but the causes of it in the past were put down to original unequal spreading of the road material, to unskilled rolling, irregular consolidation, insufficient or irregular foundations, excessive watering, in fact to many causes other than the one now brought forward by the author. Everyone knew the roads were wavy, but no one assigned the waviness to what the author believes is the chief cause, that is, the repeated action of vehicles, closely resembling one another in their harmonic action, passing over the road at a speed sufficient to transform the smooth rolling of the wheels into a bounding or pulsating motion. Professor Archibald Sharp came very near to this conclusion in discussing a Paper read by the author on the subject of Road Vehicles before the Institution of Automobile Engineers in 1906. He asked the audience to consider what happened when a car running at 30 miles an hour traverses a road having waves, so often met with, with a length of 2 feet from crest to crest, and a height of 1 inch from trough to crest. Every part of the mass of that car which partook of that slight vertical oscillation was moved upwards and downwards 1,320 times in a minute, and the acceleration given to that mass was the same as that of an engine of 4 inches stroke making 460 revolutions per minute. He then said that engineers had directed much time and attention to the reduction of weight of the reciprocating parts of their engines, and he thought it was time they paid a little more attention to keeping down the weight and controlling the movement of the mass of the car which must partake of this up-and-down movement. He pointed out that with a London motor-omnibus, even at the reduced speed of 15 miles an hour, the forces were considerable; that the upward forces to be given to the axle were even then six times its own weight.

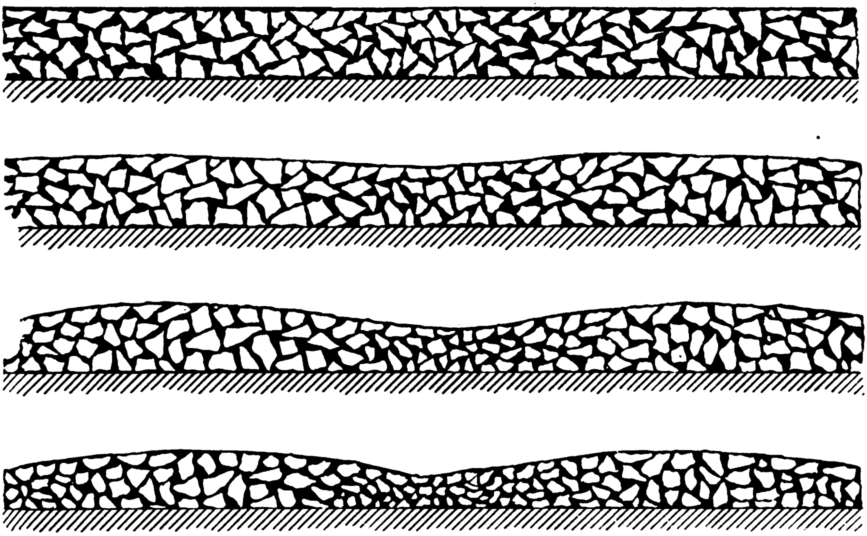
If Professor Sharp had gone a little further, he would have seen that it is this up-and-down harmonic motion of all motor-vehicles, only partly absorbed by their springs and which can be originated by very small waves existing when the road surface is first made, that tends to increase these waves, and that this intensifying wave-forming action is most rapid and harmful to a road when the period of the cars harmonizes very nearly with the period of the waves already formed on the road, or is a multiple of that period.

Mr. Lanchester, who has thoroughly studied the whole theory of the springing of cars, in a discussion which followed the author's Presidential Address to the Institution of Automobile Engineers in 1907, said that, logically speaking, heavy traffic moving below a certain speed limit ought to counteract the wave-forming effect of the high-speed traffic, which he admitted was largely due to the rebounding or percussive action above alluded to. He also went on to say that when the speed is low enough to allow the wheel to roll smoothly over the wave crests without such rebounding action, and the fact that during the time the two convex surfaces are in contact when the wheel is passing over the crest, it diminishes the contact area automatically and it ought to increase the wear at this point, and conversely to diminish the wear at the bottom of the trough of the wave. He (the author) thinks it is not probable that speeds low enough to produce this beneficial effect are ever observed, so that its effect must be negligible.

The next point requiring investigation was to determine, if possible, the manner in which the materials forming a road surface are moved into new positions when the wave formation is in progress or complete. When a wheel rolls over any surface, the individual particles of which that surface is composed must be rocked to and fro by the rolling action of the wheel, and the model shown is an attempt to demonstrate this rocking action. It is true that in the model the particles are supposed to be cubical in form, but the same rocking action must take place whatever their form may be, and it is practically certain that it is greatly intensified when pulsating or percussive action of the wheels is substituted for smooth rolling.

It will be readily seen that, with roads made up as they now are with particles of regular size, they must in the action of rocking abrade one another and so wear away their angles and gradually alter their shape from the sharp angular form of the new road material until they approach a spherical shape. In a well-designed newly made road of the existing type angular pieces of stone of a definite size or gauge are used; the voids between these stones are partly filled with smaller angular pieces and with sand and fine material, so that when the whole is consolidated by the roller, the rocking action of the wheels of the traffic is resisted to some extent by the angular interlocking of the stones and sand. It is evident that, as the stones lose their angles and become rounded, a time comes when they can actually roll over and thus transfer themselves to new positions, being propelled to these new positions by the percussive action of the wheels. This has a greater effect on the larger than on the smaller stones, so that in practice, when one examines cross-sections of the crust of any

FIG. 4.—*Diagrams Showing Movements of Pieces of Stone.*



roadway that has been subjected for some time to the action of traffic and that has acquired a waved surface, one finds the smaller rounded stones underneath the troughs and the larger stones underneath the crests of the waves. Fig. 4 (page 1265) is an attempt to show this, and it is here pointed out that the author's observations on this matter have been made on a very large number of cross-sections of roads exposed by the operations of the Water Board, and other authorities, when laying pipes or in similar road operations.

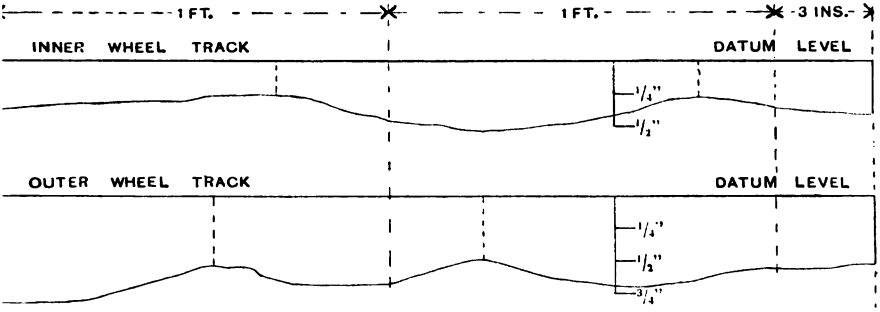
The wave-forming action of the modern self-propelled vehicle is far more intense than could have possibly been the case with horse-drawn traffic, one reason being that the speed being greater, the change from true rolling to pulsating action is therefore greater. The wheels as a rule are of smaller diameter, are more equal in size, and the general harmonic characteristics of the mechanically-propelled vehicles resemble one another far more closely than was the case with horse-drawn vehicles; for of the latter many were slow-moving two-wheeled springless carts with wheels of large diameter, others were light carts or four-wheeled wagons with unequal sized wheels. There was also the blow of the horses' feet, which must have a considerable modifying effect on the road surface; therefore, in all essentials, the conditions of horse-drawn traffic were far more heterogeneous and non-harmonic than the new traffic.

Again, commercial vehicles now consist of large fleets of wagons or vans which are practically identical in all their harmonic features, and as these run over roads as regularly as a train service on a railway they have a severe harmonic effect on their surface. If we examine the effect of a line of motor-omnibuses all having the same characteristics of total weight, of unsprung axle-weight, period of springs, length of wheel-base, vibration of engine, and which traverse a road at approximately the same speed at regular intervals of time, it is not surprising to find that, with such traffic, wave formation amounting to cross corrugation is rapidly set up, and that roads of the old type become broken up from this cause in a few months, and that the wave formation produced is very regular and definite in wave length.

Machine for Comparing Efficiency of Methods of Road Construction. —A further confirmation of this wave formation has been obtained from the experimental work carried out with the road machine at the National Physical Laboratory. At an early stage in the test of trial roads at Sidcup and elsewhere, it was seen that the best of the systems of modern construction would take years of heavy traffic to develop any measurable wear or even deformation. The author was called upon to design a more rapid method of comparing the efficiency of new methods of road construction, by subjecting the material laid in a circular roadway, or path, to the wear of wheels driven by electric power. The construction of such a road machine was sanctioned.. The author collaborated with Dr. Stanton in the design of the machine, which was completed and set to work early in 1913. Fig. 8, Plate 43, gives a general idea of its construction. It will be seen that it consists of a circular path, in which is laid the special road-surface to be tested. On this circular path the frame carrying eight wheels revolves at any desired speed from 3 miles up to 20 miles an hour. The wheels at present in use are 1 metre diameter, 3 inches wide, and can be loaded up to 1 ton per wheel, or about 800 lb. per inch width of tyre. Eight of them therefore cover 24 inches as the extreme width of the test path, but in order that they may not leave ridges

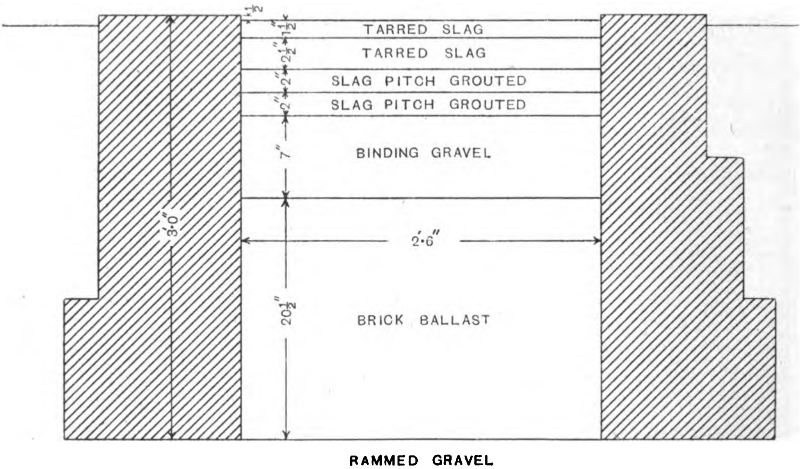
Fig. 9.—*Endurance Test in Model Tar Macadam Road.*

Longitudinal Contour after Test. 2-inch Material.



or ruts in the tested surface, each of the wheels is provided with a positive end-traverse of 1 inch inwards and outwards from its fixed radial position. It makes this complete traverse of 2 inches in one-and-three-quarter complete revolutions of the frame. The wheels are spring loaded; they are attached with the motors that drive them to hinged frames, and are pressed into contact with the test road by springs held down by a revolving eight-armed cantilever frame immediately below the hinged arms. The upward pressure on the hinged arms is absorbed by a ball thrust-bearing on the central pillar. It is intended eventually to vary the diameter of the wheels, and to test wheels fitted with various forms of rubber tyres. Means are now provided for measuring the shape of the surface due to wear or deformation, and the path itself is to be heated, cooled or wetted to imitate weather conditions.

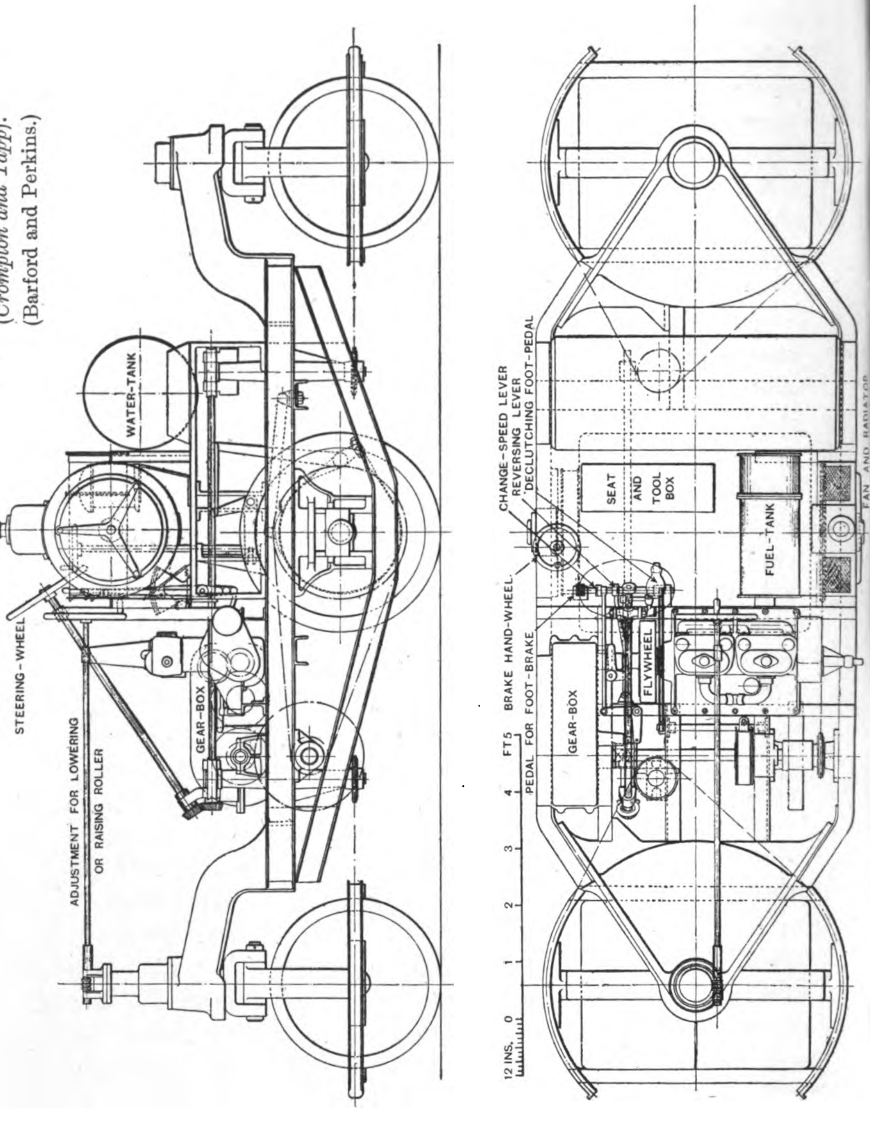
Fig. 10.—*Road-Construction Machine, N.P.L.*
Cross Section through Path.



All the tests that have been hitherto carried out show a marked tendency to produce wave deformation. The machine itself has a harmonic period, and this reduces the time necessary to test a surface, and to compare its merits with others in resisting this wave deformation. The diagram, Fig. 9, shows the actual waves produced by this machine on a tar macadam surface, supported on a foundation shown in cross-section in Fig. 10. Although valuable information confirmatory of the author's ideas on wave formation have already been obtained from the running of this machine, he does not pretend that during these preliminary tests they have more than touched the fringe of this important subject, but there is little doubt that they will eventually obtain information of a valuable character, both as regards the cause of the wave formation and the best methods of resisting it.

Initial Waves on newly-formed Road Surfaces.—In considering what might be done to improve the vehicles so as to minimize their tendency to deform the road by way of formation, the author's ideas were first directed to the original initial waves, which are always found to some extent on newly formed road-surfaces. The chief reason why no surfaces but those of wood pavement, or of the sheet asphalt laid with a trowel and adjusted by hand-beaters, are free from initial harmonic waves, is that the road-roller used when, as is usually the case, the rolling is carried out in the direction of the line of traffic, however skilful the operation of rolling is performed, always produces waves which eventually are intensified by the traffic; for when an ordinary two-axle roller is first brought on to newly spread road material, it alternately pushes the material forward until a certain resistance to forward movement is encountered, and then rolls over the accumulation thus formed in front of it. This alternate action is periodic, and the wave length depends on the diameter of the roller-wheels, the total weight, the distance between axles, and to some extent on the speed at which the rolling is carried out, but in all cases the finished surface is waved. It is found to be much easier to roll to a surface of small wave height certain soft road materials, such as blast-furnace slag or some of the limestones, than is possible with the harder and more incompressible granites and basalts, but in no case is the finished surface ever truly flat and waveless. When the traffic comes on to the road, there is little doubt that the small waves left by the rolling serve as a starting point for the shorter-period waves

FIG. 11.—*Three-axle Motor-Roller* (*Crompton and Tapp*).
(Barford and Perkins.)



eventually formed by the traffic itself; and as it appeared to the author that all two-axle vehicles must cause this action, it occurred to him that it would be better to commence by modifying the design of the rollers themselves so as to produce a non-wave-forming roller. He has succeeded in doing this by adopting the three-axle principle, and it is probable that the same three-axle principle might be with advantage extended to all vehicles carrying heavy loads.

Three-Axle Roller.—The idea of designing this roller came to the author when he was studying the three-axle wagons used by Colonel Renard for the well-known Renard train. Colonel Renard's ideas of perfect road transport were that all the vehicles of his train should be provided with three axles, and they are the only vehicles which the author has seen in use which have a real tendency to correct the wave formation caused by the ordinary two-axle vehicular traffic. These experiments showed that the Renard train was exceedingly easy on the road. The rolling resistance, and therefore the power required to propel the train measured by its fuel consumption, was found to be very small, and this has confirmed the author's ideas that much might be done by the designers of vehicles developing this three-axle principle. Fig. 5, Plate 43, and Fig. 11 show the three-axle roller that has actually been constructed and is in use, and which has certainly produced surfaces freer from waves than has heretofore ever been the case.

In order to obtain a perfect levelling action of the rolled surface, the weight taken by the three rollers must constantly vary so that it can exert maximum pressure on the high places and a minimum pressure on the low ones. At the same time there must never be less than sufficient weight on the centre driving roller to enable it to have the required driving adhesion. In this design these conditions are met by mounting the centre roller only on springs, in such a way that it can fall below but cannot rise above a fixed point relative to the front and rear rollers. The action of the rollers is then as shown in the following diagrams. In Fig. 12 the front roller is seen on the summit of a wave or high place, the centre roller having sunk below its normal position, which is indicated by the dotted lines; when the centre roller passes over the same summit as shown, it takes practically the whole weight of the roller, which tends to reduce its height. If the centre roller were not provided with springs as described, the rear roller would tend to leave a depression when in the position shown in this figure. Fig. 13 shows the action of the machine when rolling freshly laid road material; it will be seen that the rolling surfaces of the rollers are not quite in the same plane, but that the centre one is then slightly below the level of the other two. This gives a very light pressure during the first time of rolling, which gradually increases each time the roller comes back on to the cooler and harder material already rolled; this is due to the fact that, as the road surface becomes less yielding, the weight becomes more concentrated on the central roller, giving the much-desired effect, just as if a light roller was first employed followed by a heavier one, but the change from light to heavy being more gradual. The difference in the level of the rollers is adjustable by the arrangements shown on the front steering-head and extends over a range so sufficient that, if necessary, the rear roller can be permanently raised from the ground, concentrating 90 per cent. of the total weight on the centre roller. The front roller always has sufficient excess of weight to give steering effect. The drawings show that the wheel-bases are not equal. This is purposely arranged as a further precaution against the possibility of producing

FIG. 12.—*Diagrams showing Action of 3-axle Roller.*

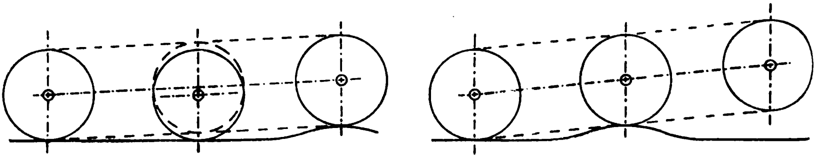
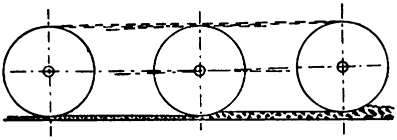


FIG. 13.



Rolling freshly laid Material.

recurring waves. In the present design the diameter of the centre roller is 3 feet 6 inches, and that of the end rollers 3 feet, but in the new design the centre roller has been altered to 4 feet. The width of the rollers over all is 4 feet, the long wheel-base 8 feet, and the short wheel-base 6 feet 6 inches. The distribution of weights can be varied by the hand-wheel adjustment, between the limits given in the Table below, with corresponding rolling-pressure variation of from 160 lb. up to 500 lb. per inch width of roller.

Front axle.		Centre axle.		Rear axle.		Total.		—
Tons.	Cwts.	Tons.	Cwts.	Tons.	Cwts.	Tons.	Cwts.	
0	17	8	10	—	—	9	7	Without water ballast.
3	8	3	8	2	11			
0	17	10	13	—	—	11	10	With water ballast.
4	2¼	4	2¼	3	5½			

Large Wheel-Diameters.—Apart from the adoption of the three-axle methods, it is necessary to point out in what direction designers of road vehicles can modify their vehicles, so as to reduce the cost of road maintenance for given weights transported at given speeds. When rubber tyres are used, the shocks imparted to the road are so cushioned by the tyre itself that increased wheel-diameter is not of great importance, but when the problem of carrying considerable weights at a paying rate of speed, say up to 8 miles an hour, at the lowest combined cost of the vehicle and the road is attacked, it will be found that much can be done with steel-tyred wheels by very considerable increase in the diameter of the driving wheels. No one has appreciated this so much as traction-engine designers, who for many years past have been aware that the large and heavy engines necessarily used by them to haul paying loads could only be tolerated on our roads when the driving wheels used are 6 feet in diameter and upwards.

For a long time designers of motor-wagons and light tractors were fettered in the use of large wheel-diameters by their great weight, but now that the suspension principle, where the whole of

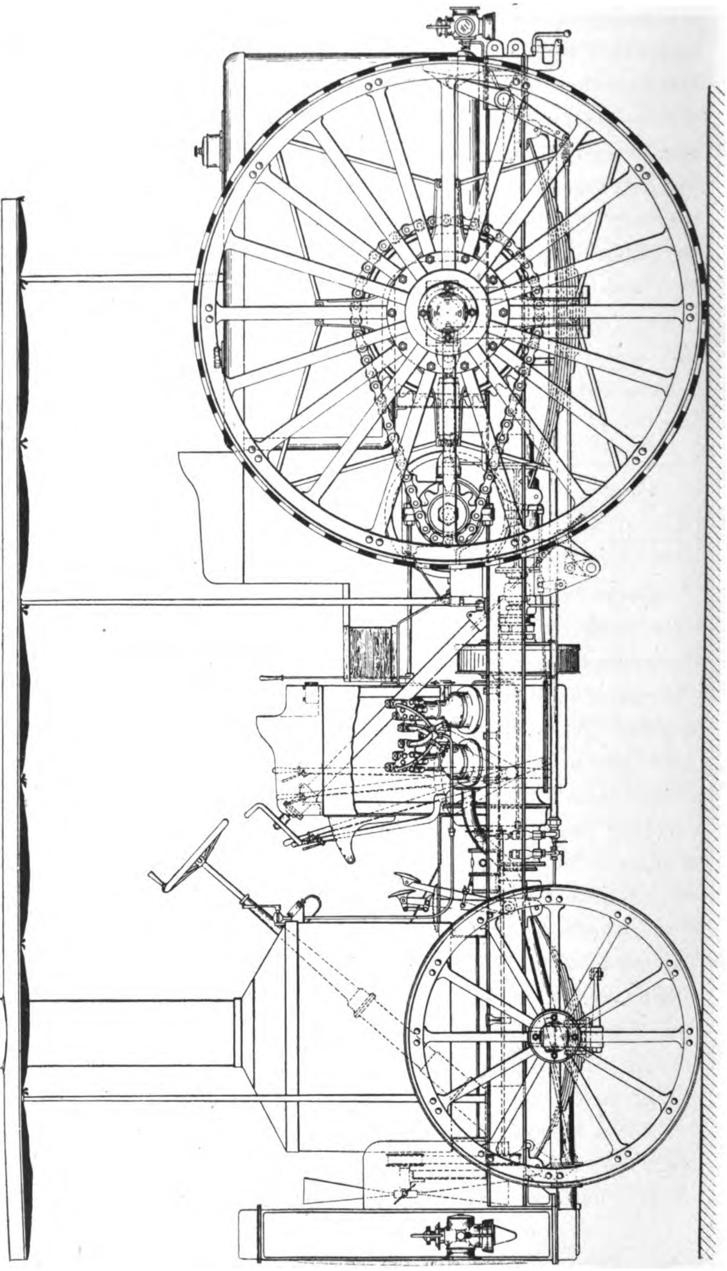


FIG. 14.—*Light Military Tractor with 7-foot Driving Wheels.*
Designed and built for the Aldershot Military Trials in 1909.

the spokes are in tension, is available, very large diameter wheels can be used with small increase of weight. The author, feeling that this was the case, designed a tractor, which he believes is the first of its kind, to utilize 7-foot wheels with a comparatively light axle-weight. Fig. 14 shows this big-wheeled tractor, which was tried experimentally with successful results. It was very remarkable to witness the smooth running of this tractor when hauling considerable loads over soft roads having very rough surfaces, and at any rate for military purposes or for colonial development such a method of reducing the cost of maintaining the roads is worthy of careful consideration. Enough has been said to indicate in general terms the extent to which the vehicle designer can modify this vehicle so as to help the road engineer.

Improvement of Road Surfaces.—We now come to consider what are the chief features of road design, to enable the surface to carry the wheeled traffic of the future at a minimum cost with the least deformation of the surface, and therefore with the greatest comfort to passengers and at the lowest cost of maintenance of the vehicles that roll over it. The first great change in road construction that has already developed itself to a large extent is that of minimizing the effect of the climate on the road by rendering the road surface impermeable, by dressing it with tar, pitch, bitumen, or other bituminous substances. This tarring of the surface particles holds them together, and prevents their movement when exposed to the comparatively feeble disturbing influence of the rubber tyres of the light class of vehicles. It has enabled roads thus treated to become practically dustless for eight months of the year, but unfortunately the action of the tar does not extend sufficiently deep below the surface to hold the surface together in winter. It follows that, up to the present, tarring has been efficient only for summer use, and that in most cases one expects to see the tarred surfaces break up under winter traffic. The author for a long time believed this was solely due to want of strength or mechanical causes, but he now believes it is also due to certain surface tension properties of the tars used. He has noticed that no such action occurs in the most perfect impermeable and durable surface of all, the asphalt pavement, which stands the effects of traffic of all classes just as well in the wet and cold days of winter as in the dry days of summer.

Reconstruction with road material coated with Bituminous Binders.—Up to the present, road engineers have addressed themselves to resisting the surface deformation caused by traffic by using tar, pitch, bitumen or other waterproof binders to cement together and hold ordinary road stones and similar material by forming it into a partially elastic concrete, these bituminous binders taking the place of the Portland cement of hydraulic concrete. Their success has been considerable and progressive, and has been largely due to the employment of machinery to dry, heat, and prepare the material before it is spread and rolled down into place. Mr. Hooley, the County Surveyor of Nottinghamshire, was the pioneer of these methods of deep treatment. He was the first user of blast-furnace slag which, after being broken to suitable sizes, was tar-treated whilst still hot, or if necessary was re-heated and then dipped into or coated with good tar from the gas-works; the tarred material was spread and rolled down in successive layers, using the coarser material for the lower coat and the finer material at the top. Many miles of these surfaces have been laid and have been very successful; they have been durable, and in counties near the sources of supply of the slag have been cheap to construct and to maintain. His processes were imitated, but not always with success. It was argued that if such good results could be obtained with blast-furnace slag, which is a comparatively soft material, that even better results ought to be obtained if high-class granites and basalts were similarly treated, but from what are now well-understood causes, these expectations have not been fully realized. The tarred slag macadam used by Mr. Hooley still holds its own; there have been fewer failures by its use than with any of the other road stones when such previously coated material is used.

Grouting or Penetration Methods.—The second class of deep treatment of road surfacing is by the grouting or penetration method. Clean dry stone is spread over the road, rolled down until the desired contour is obtained, and a mixture of pitch or of pitch and sand is poured so as to fill the voids an inch or more below the upper surface; the surface is again rolled and finished with fine material. Both systems have had their advocates, and the requisite machinery for producing both classes of surfaces is hereafter described.

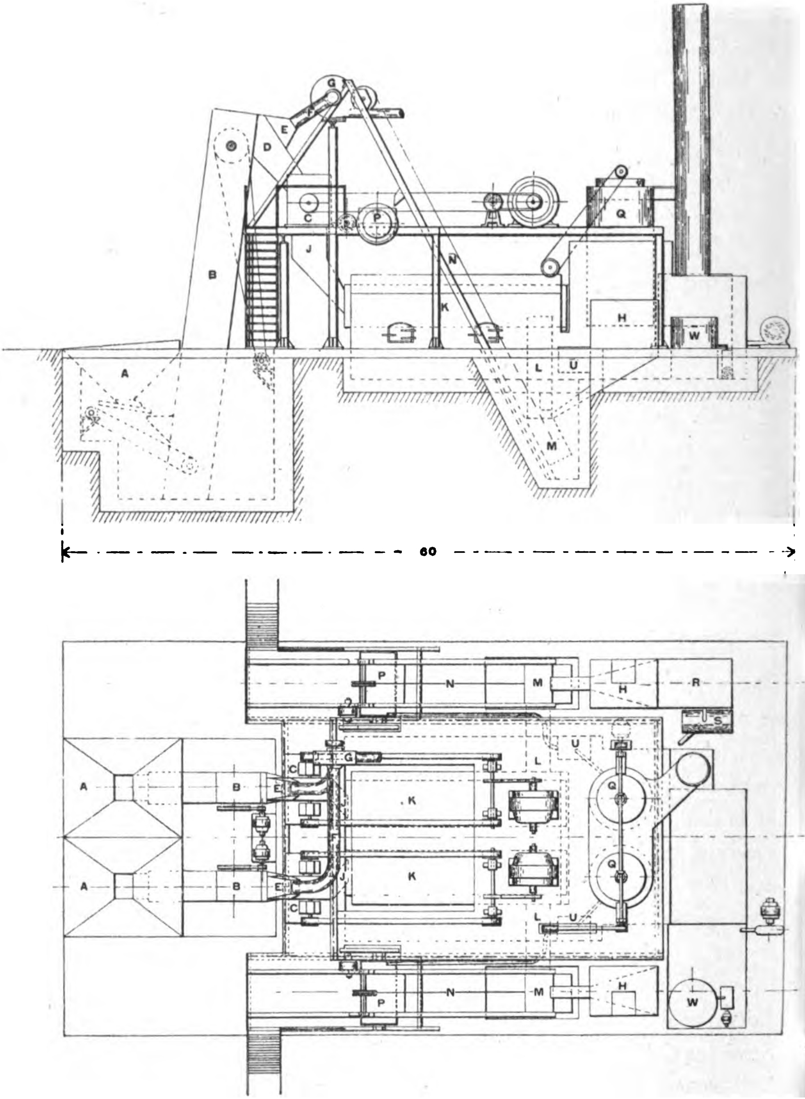
Sheet Asphalt or Double-Coat Work.—Last of all, in order of time, have been the efforts to imitate as far as possible the asphalt surfaces with which we have been so long familiar in our large towns. Passing over the early stages of the asphalt industry, where ground-up rock asphalt obtained from abroad is applied to the surface of a concrete foundation in the form of a heated powder, and then compressed by hot beaters to a true surface, we have the system so largely adopted in America of producing artificial asphalt by covering a concrete foundation with a sheet asphalt artificially formed from a graded sand aggregate held together by a bituminous binder, or as the Americans call it an "asphaltic cement." If we take the heavily trafficked streets and roads of the world, there is probably now under traffic a larger area of this class of sheet asphalt pavement than of any other form of surface, and the latest efforts of road engineers appear to be in the direction of extending this method of surfacing to all classes of roads which have to bear considerable traffic. Already much machinery has been designed to produce such surfaces at the lowest cost.

When the author began to examine the road surfaces which resisted the harmonic wave-forming action of modern vehicles in the most satisfactory manner, he found that the sheet-asphalt pavements of the towns were the best and most durable, and were least deformed under traffic. They are now used in many forms. Sometimes the original and hitherto expensive arrangement of supporting the sheet-asphalt surfaces by concrete foundations has been used, but in many cases successful attempts have been made to utilize the existing macadam roadways as a supporting crust, and to lay on them a bituminous-bound new surface in one or two layers. Many examples of this have been laid in various parts of London, and the surface of the Thames Embankment from Westminster Bridge to Blackfriars may be noted; here the method adopted has successfully resisted for several years exceptionally heavy traffic with but little deformation and at a low cost. During the past year or so similar surfacing has been carried out on many of the great omnibus routes, and has certainly justified itself by the successful way in which the harmonic effect of this most difficult type of traffic has been successfully dealt with, the wave deformation being very small and not appearing to increase to any marked extent.

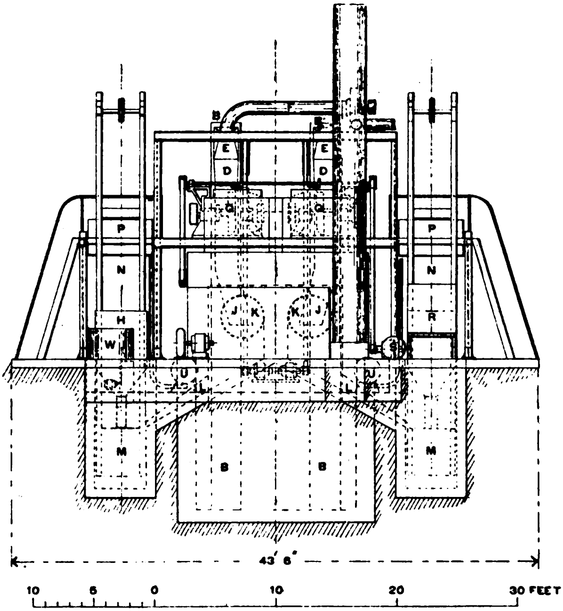
Material available for Double-Coat Work.—The success of this method has led the author to believe that we should aim at producing this class of wearing surface for all our important roads. In some cases it may be that the traffic can be successfully carried with single-coat work, the single coat being made entirely of graded sand bound together by bitumen; in other cases where the traffic is heavier double-coat work must be used. The chief condition governing the choice will be the cost. In considering the cost of surfacing, perhaps the important question is that of the carriage of the material. The cost of railway and road haulage taken together forms a large fraction of the total cost of re-surfacing a road. It is therefore most desirable to use local material wherever this can be done without affecting the quality of the work. For this reason, the author suggests that the bulk of the material forming a road-wearing surface should consist either of local sand (the distribution of which throughout the United Kingdom is very wide, so that as a rule the cost of suitable sand delivered at the roadside is only half that of good road stone), or that an ideally perfect aggregate for the wearing surface should be provided by crushing sandstone or any similar local stone which is composed of hard sand cemented together by binding matter. Such silicious stones can be cheaply and effectively crushed into a very perfect artificial sand to form the sand aggregate. In some cases the material of the existing crust can be partly utilized and crushed at one operation into part of the aggregate required. In both cases portable machinery, placed as close as possible to the point where the road material is to be laid, is necessary. There is little doubt that the artificially-produced sand is superior to the natural beach or pit sand, as each individual grain is angular and is quite free from adherent clayey or loamy matter, and it is moreover very important that the particles should be properly graded in definite proportions as to size. This grading has been carefully studied in America. Speaking generally, only about one-tenth of the weight should consist of grit or granular particles passing a 6-mesh sieve and retained on a 10-mesh sieve, about 40 per cent. should pass the 10-mesh and be retained on the 36-mesh, another 40 per cent. passing the 36-mesh and retained on the 100-mesh, with 10 per cent. only passing the 100-mesh. In order that such a graded aggregate may be cemented by the binder into a solid rock-like sheet to form the road surface, it should have added to it about 10 per cent. of fine limestone powder or Portland cement as a filler and about 12 per cent. of pure bitumen as the binder.

Machinery for preparing Sheet Asphalt.—Fig. 15 (pages 1280–1) shows the general arrangement of a semi-portable plant built up of wrought-iron framing bolted together, and carrying the machinery and transporting conveyors at two levels. This plant carries out various operations which will be hereafter considered in detail. It is designed to crush a stone aggregate to any desired size and grading, to heat, coat and mix it with the binder at the lowest cost for labour, fuel and maintenance of the machinery itself. The stone, whether new stone received from the quarry or old material taken from the road, is dumped or tipped from wagons into the hoppers A; from thence it is fed by an automatic jigger-feed into the crusher-elevators B, and thence into the crushers C through the shoots D. The crushers shown are of the high-speed rotary type, known as the "Lightning" crusher, which

FIG. 15.—*Asphalt Preparing Plant, being Combined Crushing, Sorting,* (Lightning



Heating and Mixing Plant for Bituminous Road Surfacing Material.
Crusher Co.)



is described in detail and illustrated in Fig. 16 (page 1283). The principle on which this crusher works is that the material is allowed to descend so as to meet the revolving hammers; each piece of stone is struck whilst in the air, and as the hammers rotate at a high velocity in an enclosed chamber lined with breaking blocks, the material is sub-divided and thrown with great force against the top of the enclosing chamber from which it falls again and again, being each time struck and sub-divided by the hammers. The operation goes on repeatedly until the material is small enough to pass through the screens at the base of the crusher. The number of blows made per second and the force with which they are delivered can be regulated to an extreme nicety, as the crusher is driven by an independent electric motor fitted with speed-regulating gear. With this crusher it is noticeable that the shape of the material after crushing is very cubical, there being little or no tendency to produce long stone or splinters; if it is desired to reduce the material to the fineness of sand passing the 18-mesh sieve or finer, screens can be fixed in the machine as required, but in practice it is found that for the lower coating of a road which forms the strength crust, if granite or other road stone is fed into the machine in sizes from 3 inches downwards to 1-inch gauge, the crusher can be run without screens, and the output of 15 to 20 tons per hour will even then contain nothing practically larger than ½-inch stones. Attached to the shoots D, Fig. 15 (pages 1280–1), are special chambers E connected by the pipe F to the exhaust-fan G; by this means, fine dust or any organic matter when old material is used can be separated from the aggregate, and is drawn off and fed direct into bins or disposed of as desired. When the stone is clean new stone from the quarry, this dust can be utilized in the aggregate as filler, and can be delivered at the mixer as required. On leaving the crusher the aggregate, which requires no further screening, is conveyed through the shoots J into revolving drying and heating cylinders K. The interior construction of these may be varied, one form of construction, by Messrs. Ord and Maddison, being shown later on. In addition to this there are many types of drying and heating cylinders available. These are either mounted on rollers or driven through rollers by electric motors or are suspended in chains from an overhead shaft driven by motor. By adjustment of the speed of the motors, the rate of delivery of the dried and heated aggregate can be nicely regulated to correspond with the rate at which the mixing process can be carried on.

After passing through the heaters the dried and heated aggregate falls through the shoots L direct into the buckets M of the mixer-elevators N, and after being weighed or measured close to the foot of the elevators it is dumped into the mixers P in the exact quantity required for each batch, the question of weighing or measuring being determined by the nature of the aggregate and the degree of accuracy in the mix which is specified.

The binding material, bitumen or pitch, as the case may be, and which acts as the cementing agent of the aggregate, is stored in the

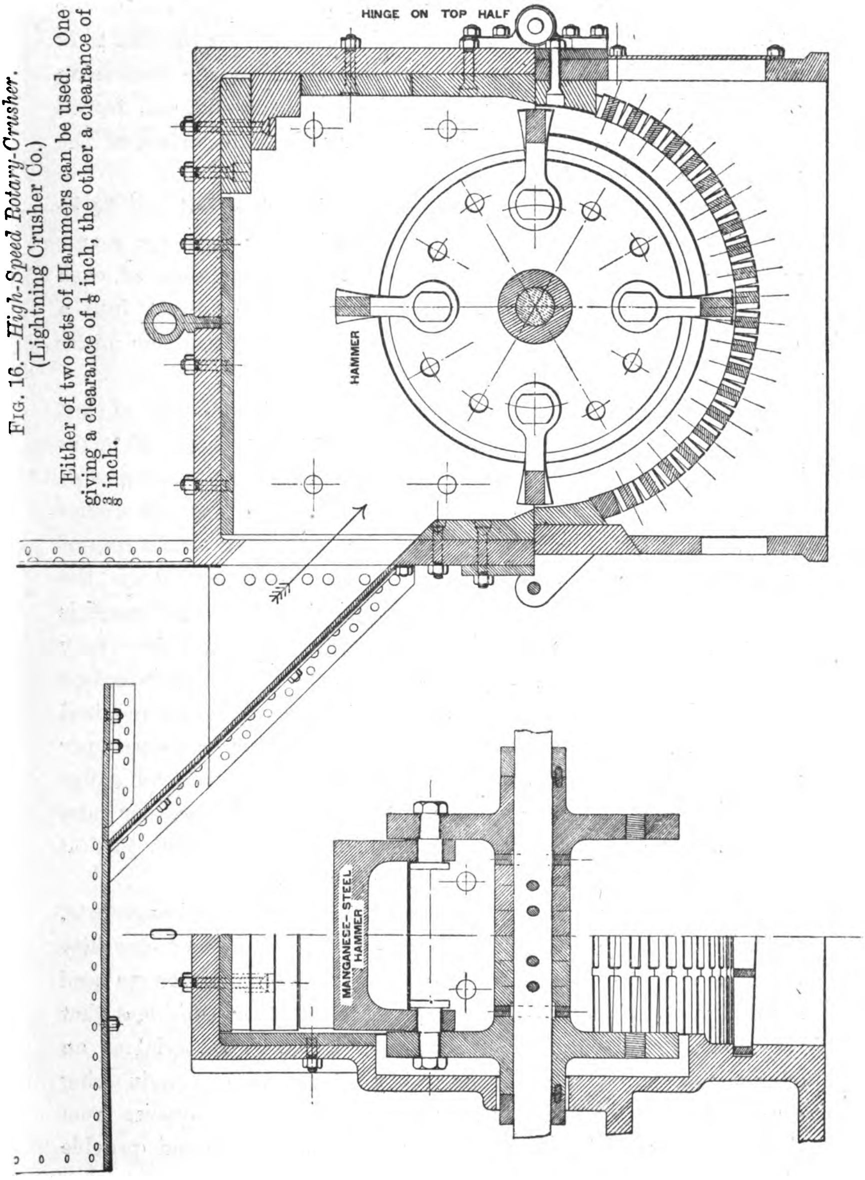


Fig. 16.—*High-Speed Rotary-Crusher.*
(Lightning Crusher Co.)

Either of two sets of Hammers can be used. One giving a clearance of $\frac{1}{8}$ inch, the other a clearance of $\frac{3}{8}$ inch.

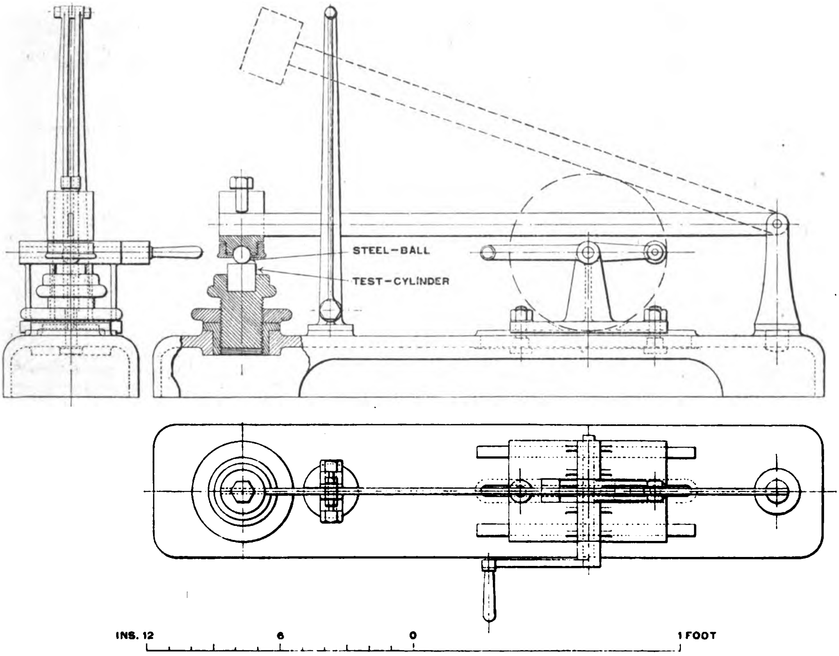
melting kettles Q in which it is melted, heated and fluxed to the desired degree of viscosity by the addition of flux from the flux tank R. The fluxed bitumen is then measured off in the measuring drums U in the exact quantity required for each mix, and forced through pipes by compressed air and delivered at the surface of the aggregate already in the mixer.

The mixers are driven by motors, and their speed can be so regulated as to give the right number of revolutions for coarse or fine aggregates as may be required. The contents of each batch when completely mixed can be discharged direct into a motor-wagon or other transport vehicle underneath the mixer platform.

With such a plant as that above described, 200 tons of hot mixture can be delivered on the road per working day of 10 hours with a proportionately greater output during the long hours of daylight in the summer months. Obviously, if the work be single-coat work either of coarser aggregate or a thinner single coat of fine aggregate, the area covered per day will depend on the thickness of the coat. Where an excessively strong road crust is required, one ton of the material forming two coats may only cover from 6 to 7 superficial yards of road, the area being increased as the thickness is diminished. With the fine aggregate required for the wearing coat, about 20 superficial yards can be covered per ton for each 1 inch of consolidated thickness. The road gangs for dealing with this hot aggregate must consist of a spreader gang and a roller gang, each double gang being generally able to deal with from 40 to 60 tons of hot mixture per day.

As the whole question of accurate grading of the sand aggregate, and the fluxing of the binder to give the degree of ductility which furnishes a wearing surface of maximum strength and durability, is of extreme importance, the author considers that the modern road engineer should test his road material as an engineer would test steel or other materials of engineering construction. He should therefore take frequent test-pieces from the batches of hot material delivered to the road, and provide himself with portable testing apparatus to enable him and his staff to make periodical tests to ensure that the materials are all that he expects them to be, and as laid down in his specification. For the purposes of such tests, it is necessary that moulds for moulding and pressing test-cylinders should be provided, and a test-hammer and press for subjecting these test-cylinders to percussive tests for toughness, and compression tests to indicate the weight-carrying quality of the consolidated roadway. Fig. 17 shows the test-hammer which has been designed as a convenient means of obtaining the toughness of the cylinders.

FIG. 17.—*Hammer for Testing Asphalt Material for Toughness.*

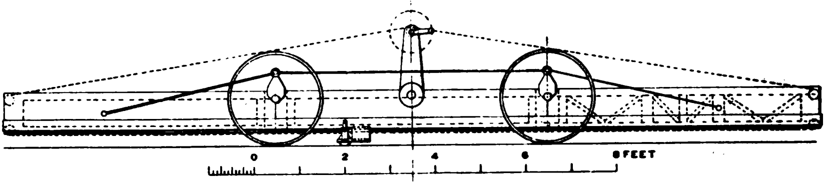


In addition to these tests on the quality of the material, the author has designed and utilized a form of portable straight-edge for ascertaining whether the roller gang are finishing the surfaces to the desired degree of accuracy and freedom from waves. Fig. 6, Plate 43, shows this straight-edge and Fig. 7 the recording carriage and pen. With this straight-edge the actual contour of the road is shown to full size, and all tendency to waves measured on the paper with extreme accuracy. Fig. 18 shows an improved form of straight-edge.

In the foregoing description, the author has confined himself to describing machinery which can now be designed to produce an up-to-date form of road surface.

Advantages of rolling down Hot Material.—The reason why the author believes it is necessary to form these surfaces of hot material, spread and rolled down whilst the material is still in a hot and plastic condition, is that although more complicated and expensive plant is required than is the case if the material can be previously treated and stored, and delivered, spread and rolled down whilst in a cold condition, that in the former case the newly-made roadway is completely set, hardened and in a fit condition to receive the traffic as soon as the material is cold; whereas in the latter case, as the material only hardens by the gradual evaporation of the more volatile oils in the binder, the process of setting is a slow one, so that the road is liable to be deformed and damaged by heavy traffic passing over it for several weeks after it has been constructed, and that the risk of the damage liable to occur during this period to a road made of cold-rolled material quite outweighs its lower cost compared to that of the more perfect hot-rolled process. But whether the process be carried on with previously prepared cold material, or with hot material which must

FIG. 18.—*Improved* 18-*foot Straight-Edge.*
For Photo of Pen Carriage see Fig. 7, Plate 43.



be spread and consolidated within a few hours of its being produced and mixed, a good deal of the plant required is the same. The cold-material plant, however, can be at or near the quarry, whereas the hot-rolled material must be prepared within a mile or two of the road. Fig. 19, Plate 44, shows the Ransome-verMehr Machinery Company's portable apparatus, in which the stone or sand can be dried and heated and coated in the same manner as in the fixed or semi-portable plant already described. The designers of this plant point out that long cylindrical driers above described lack portability, and that, for working by the roadside on the batch principle, the Ransome stone-drier, Fig. 20, can be operated so as to synchronize with the batches required, and the heaters and driers therefore are constructed in sizes having a definite batch capacity. The arrangement of the machine is such that a definite quantity or

FIG. 21.—*Stone-Drying Plant* (Ord and Maddison).
Revolving cylinder 3 feet diameter by 30 to 40 feet long.

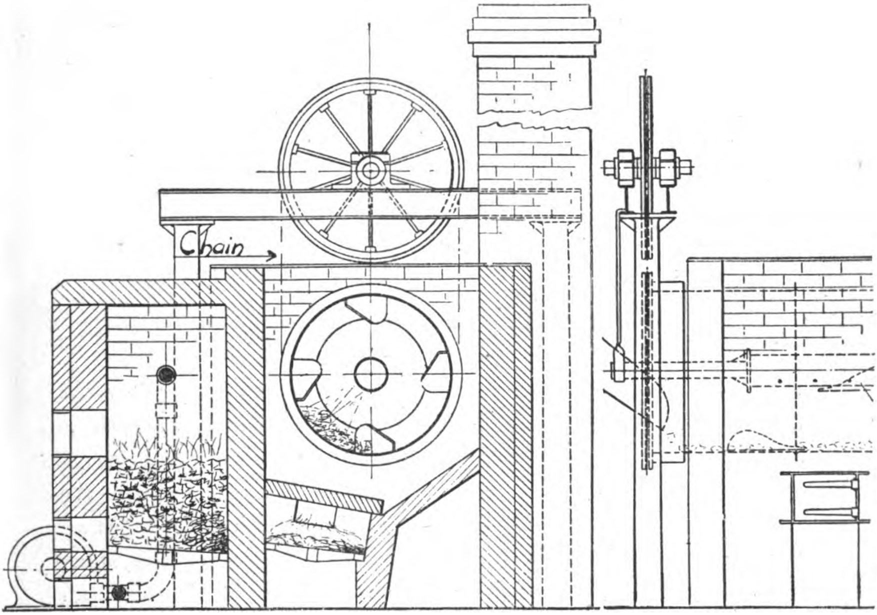
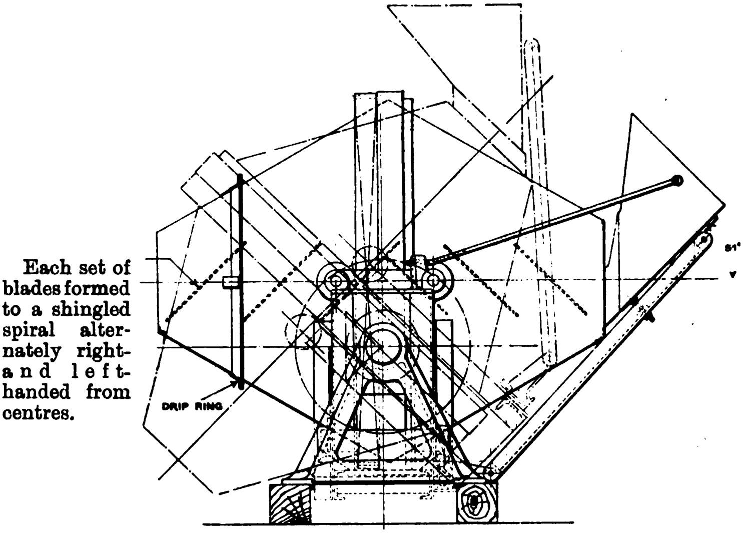


FIG. 23.—*Concrete Mixer* (*Smith*).
(Stothert and Pitt.)


Each set of blades formed to a shingled spiral alternately right- and left-handed from centres.
DRIP RING

Capacity :—Unmixed Material per batch . . . . = 13 cubic feet.
Mixed ,, ,, ,, ... = 9 ,, ,,
Power required . . . . . . = 6 H.P.
Revs. of Driving Pulley . . . . . = 180 per min.
,, ,, Drum . . . . = 18 ,, ,,

batch of stone is introduced through a measuring hopper into the drying drum, or first of one or more drying drums, where it is allowed to remain for a definite period before discharging into a second or third drum as necessary, and from thence direct into the batch-mixer. The general principle of this smaller drier is that an excess of heated air is forced over the surfaces of the stone contained in the rotating drier, the size and weight of which can therefore be greatly reduced.

Cylindrical Driers.—However, where ordinary cylindrical driers are used, as in the combined plant first described by the author, their general construction is that shown on Fig. 21, which gives an end cross-section of the fixed cylindrical driers and heaters of Messrs. Ord and Maddison. In this the aggregate entering at one end is made to traverse the entire length of the cylinder

FIG. 23.—*Concrete Mixer* (*Smith*).

(Stothert and Pitt.)

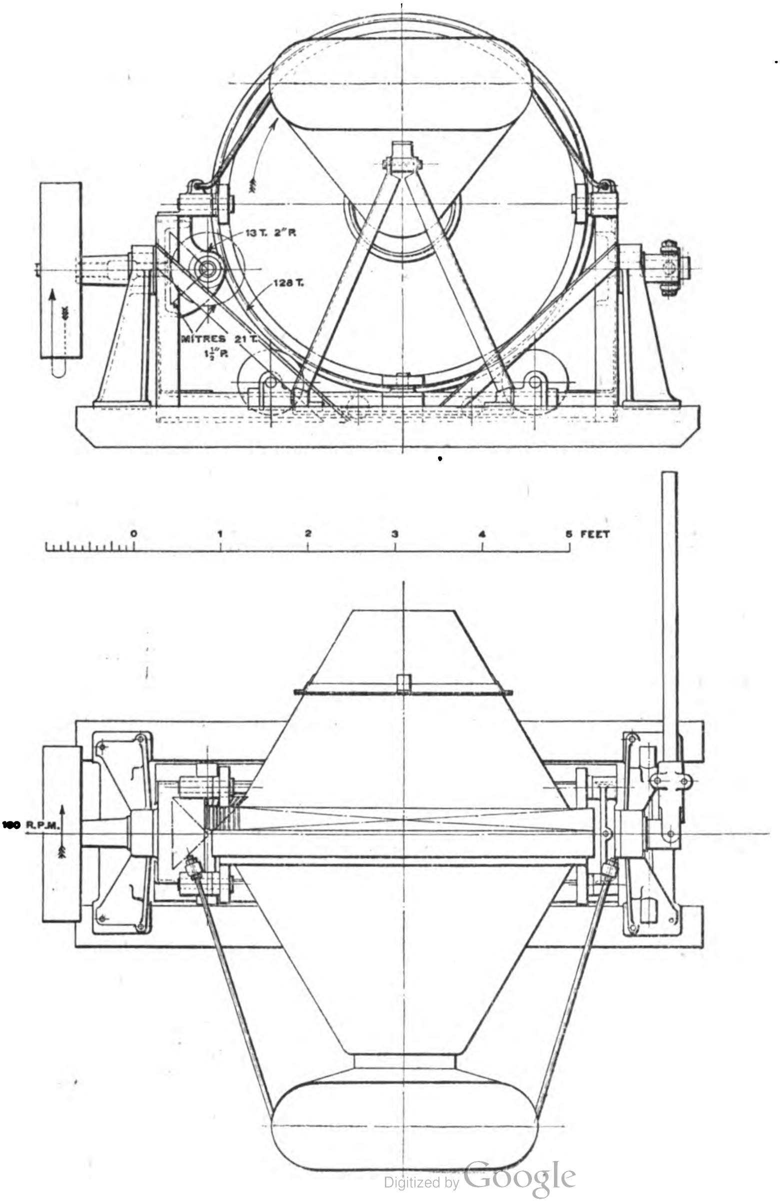
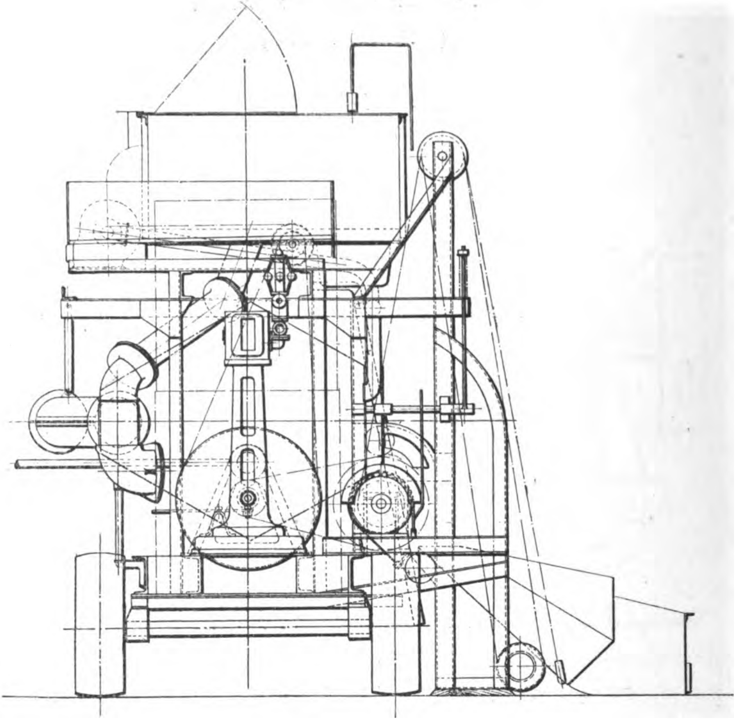


Fig. 24.—*Portable Hot Mixer and Boiler* (*Smith*).
(Stothert and Pitt.)



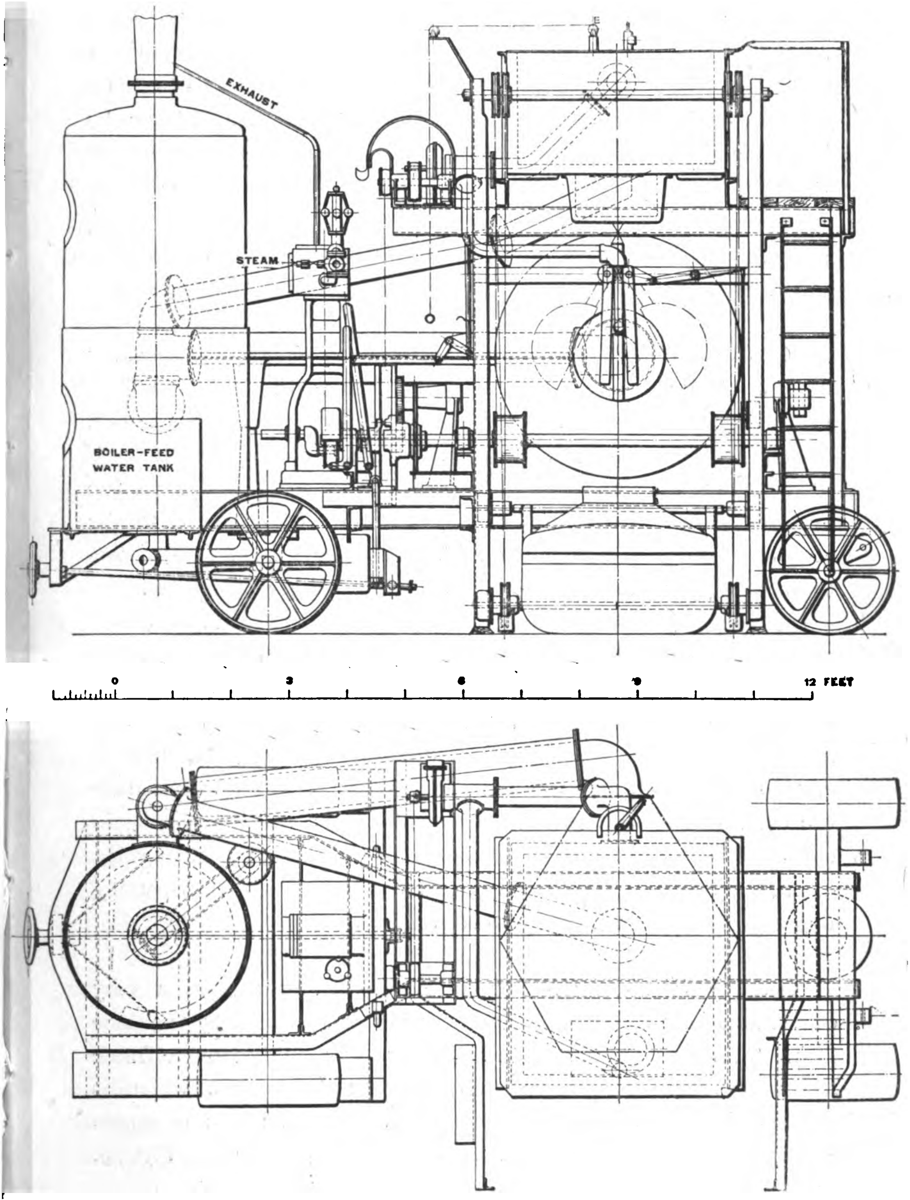
by suitable helically-formed guide-plates, and is discharged thoroughly dry and at the required temperature. The end section shows very clearly the method of suspending the rotating cylinder by chains protected from the action of the hot gases. In this case, air heated in a special retort is brought into contact with the aggregate in the cylinder by means of the blast-pipe shown, which is provided with vent holes on its underside to direct the hot air downwards into contact with the material to be dried.

Batch Mixers.—The batch mixers generally used are single-shaft or double-shaft. In the former a single-shaft, on which the stirring

FIG. 24.

Portable Hot Mixer and Boiler (*Smith*).

(Stothert and Pitt.)



blades are keyed, rotates in a mixing-chamber, the casting of the lower half of which is curved concentrically to the revolving shaft so that the points of the blades rotate close to it to prevent any jamming of the stones. In some cases means are adopted to allow the blades to spring backwards and thus avoid fracture of the arms if a stone jams. The double-shaft mixers contain two shafts with their revolving paddles; these are geared together so as to revolve in fixed relation, and the same precautions must be adopted to prevent jamming. Fig. 22, Plate 44, shows a double-shaft batch-mixer of the Ransome-verMehr type.

Conical Rotating Mixer.—For the same series of operations the conical rotating Smith mixer, made by Messrs. Stothert and Pitt, possesses certain advantages. One of these mixers is shown on Fig. 23 (pages 1288–9), the material being fed in batches, a measured quantity of binder added, mixed and discharged direct to the transport wagon when used hot on the road, or conveyed to the storage if intended to be used cold. Fig. 24 (pages 1290–1) shows views of the Smith hot mixer plant arranged in portable form. In this portable apparatus the hot gases from the boiler furnace are used as a means of drying and heating the aggregate, the gases being propelled by a blower aided by an exhauster through a combined mixing and drying chamber. In this case the process consists in filling the mixer with the required quantity of aggregate, which is rotated and dried, and when it reaches the required temperature the rotation is stopped, the binder is added and the rotation again continued until the mixing is complete, and then, by tilting the drum, the contents can be discharged direct into the transporting wagons or hand carts as may be convenient.

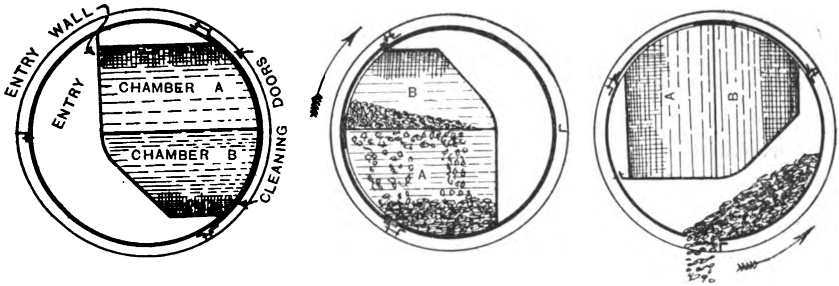
Rotating Hand-Mixer.—For small work and repairs a very convenient form of Smith hand-mixer is manufactured by the same firm. This consists of a rotating chamber mounted on a frame somewhat resembling a portable winch; the drum, which is suspended by chains, contains a spiral diaphragm; this is shown clearly in the three end sections of the drum given on Fig. 25.

The drum can be charged with material, and when rotated in one direction retains and mixes its contents; when the rotation is reversed the mixed charge can drop out into a barrow or hand cart.

Combined Heating and Mixing Machinery.—The combined heating and mixing machinery is used by the Limmer Asphalte Paving Co., whose name is so well known in connexion with the sheet asphalt pavements, and they are now extending their operations very successfully to the coating of country roads with asphaltic surfaces. With this machinery, which is of the portable type and can be readily moved to any desired position at or near the road to be treated, the same series of operations of drying, heating and mixing are carried out without any intermediate hand-labour, the finished mixed material being discharged in batches into the barrows or other means of transporting it to the road.

Fig. 25.—*Rotating Hand-Mixer* (*Smith*).

Section of Drum.



Economical Considerations.—As it is obvious that, if we wish to obtain the best results, using any of the various forms of road-making machinery herein described, the plant should be worked by trained labour under skilled engineering superintendence, it is the author's opinion that for some time to come, the work will be carried out by responsible contractors, although in some cases existing road authorities may elect to provide themselves with their own plant and to train their own staff. In either case the actual cost of re-surfacing the roads by the most approved methods will depend greatly on the extent of road work that can be carried out from each working depot, and of course on the cost of local material, cost of carriage, road haulage, etc. The choice of method depends very greatly on this last consideration, but in any case it is evident that the economical problem is to produce a modern road surface which will not break up and furnish loose gritty material to wear away the rubber tyres of the vehicles, and which will be sufficiently waveless to diminish the wear due to road shocks. Such a road must be produced at a cost per unit of surface which when divided by the years of its life will compare favourably with the present cost of the waterbound macadam superficially tarred which it will supersede.

The author concludes by showing in tabular form the extent to which the running costs of vehicles, as they are, will be reduced by well-considered reconstruction of road surfaces. In order to bring into comparison the data which are obtainable from the old type of roads with those obtainable from reconstructed roads, in the preparation of this statement he has adopted the following assumptions:—

(1) That we take the case of a mile of road carrying a traffic of 1,000 tons per day, or 360,000 tons per annum.

(2) That it is assumed that, of this traffic, two-thirds will be in the form of pleasure vehicles or light commercial vans weighing from 1 up to 2½ tons, or averaging 1·75 tons each, and that the one-third balance is in the form of 24,000 heavier vehicles between 2½ and 7½ tons, averaging 5 tons.

(3) It is assumed that the damage done to roads by a ton of traffic carried on steel tyres is one and a half times that carried on rubber tyres.

(4) That the cost per vehicle-mile for the lighter class, the bulk of which use pneumatic tyres, may be taken at 8·25*d.*, and that of the heavy 5-ton vehicle be taken at 16*d.*, both of which are well-ascertained average figures.

(5) That the cost of the roads, as they are, is the common case where a main road 18 feet wide requires re-coating every 3½ years,

at a cost of £800 per mile, or £228 per annum, which, with the annual cost of trimming and share of lengths-man's wages, brings the total cost to £300 per annum. The reconstructed road to be re-surfaced with double-coat work, 4 inches thick, at a cost of £3,400 per mile, having a life of 12 years, which, with the item for lengths-man's wages, also comes out at £300 per mile per annum.

(6) That the reduced vehicle costs shown are those now obtainable from vehicles running most of their mileage on well-surfaced urban roads, and are due not only to savings in fuel and repairs, but to the greatly increased speed and increased mileage run by each vehicle on the improved roads.

Table showing how Running Costs are reduced by Road Reconstruction on One Mile of Road carrying 1,000 tons a day.

Traffic.				Costs as they are.				Costs as they will be.			
				Vehicle.		Road.		Vehicle.		Road.	
Class.	No. of Vehicles.	Average Weight.	Total Tons.	£	Per Vehicle-Mile.	£	Per Vehicle-Mile.	£	Per Vehicle-Mile.	£	Per Vehicle-Mile.
		Tons.			*d.*		*d.*		*d.*		*d.*
Light	137,000	1·75	240,000	4,700	8·25	180	0·316	4,280	7·5	180	0·316
Heavy	24,000	5·0	120,000	1,600	16·0	120	1·2	1,200	12·0	120	1·2
Total	161,000	2·25	360,000	6,300	—	300	—	5,480	—	300	—

The large saving shown, amounting to upwards of £800 per annum to the owners of the vehicles using this mile of road, brings forcibly before the members the case which the author has attempted to make; that the time has arrived that this problem of the new industry of road locomotion should be most carefully considered by all classes engaged in it, not only the engineers whom he is now addressing, but the capitalists whose financial aid is necessary for further developments, so that the community as a whole will benefit from the increased rapidity in deliveries of the goods they require and in the future reductions in the rates of transport. There is little doubt that, when once the economical advantages of improving the road transport of the United Kingdom are thoroughly understood, a long step will have been taken towards a better distribution of our town population from crowded centres into country districts, and at this point he leaves the subject for consideration and discussion.

The Paper is illustrated by Plates 43 and 44 and 16 Figs. in the letterpress.

Discussion.

The PRESIDENT said that all the members had listened with enthralled interest to the delivery of the Paper by Colonel Crompton, and he felt sure that the care the author had exercised in preparing the information which was contained in it, and the care with which he had placed that information before them in a form which even those who had never studied questions of roads before could appreciate, entitled him to a very hearty vote of thanks, which he now asked the members to accord.

The resolution of thanks was carried by acclamation.

Sir JOHN I. THORNYCROFT said he had listened with great interest to the Paper that had been read, because the author had shown most clearly that it dealt with a subject which might be scientifically studied with very great advantage. He had personally examined some of the work that had been done, where a solid foundation had been formed and the surface which had to be renewed had been made as described in the Paper, and although he could not speak from any practical experience of road making, that method commended itself to him as being a most advantageous one. The author had stated that a sound surface could be made to a road which would not become wavy, and which would reduce very much the wear and tear on vehicles, a large saving thereby being obtained. If the author's figures in that respect were correct, it should be the aim of all mechanical engineers to endeavour to bring about such a state of affairs. The fact that a surface of a road was not watertight in some cases was the cause of the wavy form of road that sometimes occurred. In the old roads where no tar was used, and where water was very liable to lie in hollows on the surface of the road, the tendency was for the roads to become soft in these parts, and the pounding action of vehicles which had been so well described had, under those circumstances, an even greater tendency to increase the depth of the waves, owing to the heavy weight falling on a comparatively soft surface.

Mr. J. C. **Mackay** (Ludlow) said he did not anticipate that he would be called upon to speak, because, instead of being a road maker, he produced the material that was used for the making of roads, and he thought the discussion would better come from those who were engaged in the construction of roads. He desired to mention, however, that some years ago when it was desired to maintain cheaply a road in Shropshire, the surveyor, instead of using the stone which was generally used in a cubical form, repaired the road with sett-makers' chips, which was a very flat stone. That road carried the traffic for 11 years, and a large portion of the traffic during that period was in connection with the construction of the Birmingham Waterworks. From the experience gained in the use of that stone, it seemed to him that if cubical stone, after being in a road for some years, took a spherical form, as shown by the author, the best way to prevent it becoming of spherical form would be to make the stones as flat as possible. During the past month he had made a very short piece of road with sett-makers' chips, 6 inches thick, on a rather soft bottom. A 12-ton roller was put over the road, and it did not compress the chips more than about half an inch. If the road had been made of cubical stone, it would have been compressed very much more.

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He would like to add that, however good the surfacing material might be, a satisfactory road could not be made without a good foundation, and there were very few roads in this country that had satisfactory foundations. Tarmac was no doubt a good material, but satisfactory roads had also been made with high-class granites and basalts, if the matrix used had been of a high viscosity. There were several examples of such roads in Gloucestershire, Shropshire, and Herefordshire.

Mr. T. G. **Marriott** (Trinidad Lake Asphalt Paving Co.) said that, from the point of view of those interested in the construction of roads to meet the new conditions, the most encouraging feature of the Paper was the inference which might fairly be drawn from page 1255 as to the possibility of standardization of haulage systems in the near future. The present difficulty was largely caused by the wide variation in wear effect of rapid moving rubber-tyred traffic and slow steel-tyred vehicles using the roads. In his opinion, a closer uniformity in this direction would easily allow a type of road to be evolved which would fully meet the required conditions. It must be obvious that the surface flexibility of road paving was possible in the case of bituminous roads in exact ratio to the flexibility of the tyre using the surface in question. The present wide variation in tyre standards and load conditions prevented exact standards of road construction. If heavy loads carried on steel tyres continued to increase, it was obvious that an enormous increase of cost was to be feared on account of the necessity of greatly increasing the strength of road foundations. He therefore considered that standardization of the load-carrying conditions must be the first step towards the standardization of road construction.

It was possible that time would establish the fact that no form of block paving would stand the harmonic percussive action of self-propelled traffic. Already it was seen that this form of paving was affected by the new traffic in the direction of rapid wear at the joints of the blocks, thus setting up a form of vibration which would seem to be far more injurious than the periodic wave of sheet asphalt, both to the paving itself and the vehicle passing over it. In his opinion, sheet asphalt of the necessary flexibility was the only form of paving construction which held out reasonable hopes of being able to recover from the initial wave-effects of motor traffic. If this class of paving was to survive a long period of wear, it was almost unavoidable that it should in its first stages exhibit deformation in the manner described by the author, as the character of the compressive force exercised by the traffic was entirely different from that set up by the ordinary methods of steam-rolling while hot. Even the three-wheel axle-roller described by the author would not remove this effect. In the case of sheet asphalt, while the formation of waves might at first appear unsightly, there was unquestionable evidence that this tendency was diminished by time and traffic until, in its later life, the paving was practically without deformation. The exact opposite of this effect was to be noted in the case of water-bound macadam, wood and sett-paving. This class of surface, while practically perfect when first laid, gradually became deformed by traffic and time until the paving was so bad as to require entire renewal. Following this argument, the remedy was to be found in the general application of a flexible monolithic surface carried upon an elastic cushion of bituminous concrete, just as in the case of a railroad the traffic was carried by means of a smooth flexible rail laid upon an elastic resilient foundation of ballast. The precise standards to be followed in the manufacture of materials to compose these two forms of construction, as well as the machinery most suitable for the production of the materials efficiently and economically, were indicated by the author, and, though it might be questioned whether the general terms employed in this connexion served much useful purpose, he fully believed that he had, with this reservation, touched upon the cause, effect, and remedy of the problem of modern road construction.

Mr. A. **DRYLAND** (Engineer and Surveyor for the County of Surrey) desired to echo the thanks that had been accorded to the author for compiling such an interesting Paper. With many of the views of the author he was in agreement, with some

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he was not, and he desired to touch upon a few of the points of the latter kind. On page 1253 there was the statement that the design of self-propelled vehicles had reached a very advanced stage. He thought that was quite true so far as its power of conveying loads was concerned, but he very much wished that mechanical engineers would devote their attention to the effects it had on the road, and see if they could not modify some of those to which the author had referred. Colonel Crompton seemed to think that the deformation, as he called it—corrugation was just as expressive a word—had not been noticed very much in the past. He assured the author that it had been a worry to him for a great number of years, and he had frequently mentioned the matter to the author and others.

The statement was made in the Paper that materials laid hot had an advantage from the fact that they were less likely to form waves. He wished to point out that the diagrams in the Paper showed the opposite effect. For instance, on page 1261, where the upper diagram showed the material laid hot and the lower one a similar class of material laid cold, the section clearly showed that the deformation was very much less in the latter case. The remarks made about the use of tarred slag also went to show the same thing; and he thought it was very noticeable that in all the four trials that had been laid down by the Road Board, the material laid cold showed much less deformation than the material laid hot. He did not say that would be so in the end, because it might be that some of the material laid hot might have more elasticity and would thus recover; but he wished to point out that every kind of material he had yet seen laid hot was more corrugated, at any rate in its early stages, than that which was laid cold. He thought there would be a very large development of bituminous materials laid in the hot condition, and one of the problems to be faced was how they could be laid hot and yet an even surface be obtained. He did not know how far the three-axle roller or a multiple-axle roller would meet the case, but he was bound to say that, from the little work he had seen done by the three-axle roller, it certainly appeared to present a more even surface than with the ordinary tandem roller.

He desired to call attention to another point with regard to the formation of waves and the general deformation of roads. It was very evident that weight was an extremely important factor in the case, because if observations were made on certain of the roads leading from London on which most of the heavy vehicles travelled outward heavily laden, it would be found that nine-tenths of the defects in the road surface were shown on the near side, and that indicated to him that the weight combined with the speed was the greatest factor in the deformation of roads. He thought there was much in the point the author had made in regard to the rhythm of the wheels, and he particularly wished to direct the attention of mechanical engineers to that point with a view to seeing whether it could not be varied. It might be done possibly by a variation in the size of the wheels between the front and the back. In most vehicles at present the wheels were very much the same size.

The author had stated, in connexion with rubber tyres, that the wheel diameter was not of great importance, but he (Mr. Dryland) did not agree with him on that point. Colonel Crompton had referred to the effects of motor-omnibuses on a road as causing the greatest extent of deformation, and in that case the wheels were very much the same size and had rubber tyres, so that he did not think it could be said that the question of the diameter of the wheel, even if the tyres were of rubber, was not of great importance. He thought it was of great importance, and he would very much like to see all self-propelled vehicles made with larger wheels.

He quite agreed with the author that so far the use of tarred slag had produced very admirable results, and at the present price it held its own against anything that had been brought before his notice at the present time. He wished to point out that the author rather inferred in his Paper that the coating on the Thames Embankment was on an ordinary macadam surface. That was not the case; it was on a tarred macadam base. He and many other surveyors had, however, tried comparatively thin asphalt coats 1 inch or 1½ inches thick on the ordinary macadam crust, and so far with very promising results, the idea being that where there

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was a sufficient strength of metal to carry the weight it was not necessary to have in addition what the author called a strength crust. He felt there might be possibilities of weakness in regard to the connection between this asphaltic coat and the macadam, but so far in cases which he had in mind, even with a very thin coating of 1 inch, which had been carrying a very considerable motor-omnibus traffic for something like two and a half years, there was no evidence at present that there was any parting between the coat and the base, nor was there any visible deformation of surface.

He thought the author was rather sanguine in some of his statements in the latter part of the Paper, for instance where he stated that 200 tons a day of material could be turned out and laid. He thought it would be found in practice that it was not possible to deal regularly and properly with such an amount. He did not think either it was necessary for the statement to be made that a plant of that kind should be very near the works, although of course it was desirable. As a matter of fact, that kind of material had been laid as much as 30 miles from the works with very considerable success. It had been carried all that way hot even by the slow process of a steel-wheeled tractor, which had taken from 6 to 12 hours to get to the site of the work.

He did not wish to criticise closely the author's figures with regard to the reduction of cost in the future. He thought, however, that some of the author's assumptions were only assumptions, and that it was very likely they would not be justified by results, one of the assumptions being the life of 12 years for the surface wear of a modern road. He hoped the author might be right, but he had very grave doubts. There were very few roads that promised such a length of life at present. He also hoped that the saving in cost both on the vehicle and on the road might be such as he anticipated.

He concurred in the remarks the author had made on the question of road deformation, and wished to point out to mechanical engineers that the matter was a most important one to them, because the greater the departure from a true rolling surface, naturally the greater the wear and tear on the vehicle itself. It was well worth the attention of mechanical engineers to see whether they could not modify the design of vehicles and make such alterations in the distribution of the load as would reduce that deformation. It was a worry to those who had the charge of roads to know how to overcome deformation, because it was a very difficult matter to remedy without reconstruction, and if that reconstruction had to take place at frequent intervals, it must naturally be very costly to the Road Authorities, and probably the motor vehicles would not have such good roads to run upon. He therefore trusted mechanical engineers would do everything they could to help in minimizing the damage that was at present caused.

Mr. **Charles Hawksley** (Member of Council) desired to ask the author how, if his stipulation that the lower layer of the road formation was never to be broken was to be carried out, he proposed to deal with the laying of gas, water, telegraph and other pipes and the construction of sewers, all of which must of course necessitate breaking through the lower as well as the upper layer of the road.

Mr. **Mark Robinson** (Vice-President) would like to ask a few questions of the author. In describing the genesis of the wave formation on roads, the author spoke of the material being pushed forward in front of the wheels. He would like to know whether that advance was continuous. In taking measurements on the crests of the ridges, did they find that these ridges remained in the same spot, or did they constantly, but of course slowly, move forward under the traffic—as (to compare slow movement with fast) the waves upon water moved forward under the pressure of the wind? And, if the ridges advanced, did they advance in opposite directions on the two sides of the road, in accordance with the direction of the traffic? He would also like to hear Colonel Crompton's explanation as to why wood pavements developed similar ridges, even when resting upon concrete, and

(Mr. Mark Robinson.)

not upon loose stones. He thought such ridges certainly appeared in wood paving; for instance, he had noticed them in the wood paving of York Road, Lambeth, between Westminster Bridge Road and Waterloo Station, which had recently been re-laid with asphalt. The movement of loose stones below the wood could not of course account for the ridges in a case where there were apparently no loose stones. The hollows and ridges there must have been produced by wear rather than by movement, and why the wear should take the form of cross-ridging, as he believed it did, at least in some cases, was somewhat puzzling.

At least a dozen years ago he had seen cross-ridges in a country road where there certainly was no motor traffic of any kind, and the opinion had been expressed to him by a gentleman who had much knowledge of road making, that the ridges were due to the use, or as he put it to the misuse, of the steam-roller originally employed on the work. This was practically the same view as the author had expressed. His friend also on that occasion made the interesting remark that he had observed worse ridging produced by a single-cylinder traction engine than by a double-cylinder engine. It certainly seemed possible that rythmical irregularity of drive would accentuate the trouble. In Westminster there were opportunities for studying the ridge question, at least for those who had to drive in Victoria Street at an hour after the traffic had become small. Looking in front of one along the street one saw the lights glancing off the crests of the asphalt waves in a manner almost reminiscent of the moonlight on the waters, and the jumps of the taxi-cab from crest to crest rather helped the illusion.

Mr. **Leonard F. Massey** desired also, from a mechanical engineer's point of view, to put a question that bore on the formation of waves. The members had been told that the waves had a tendency to move forward. Did the valleys move forward also—there seemed to be no evident pressure on them—or did they stand still and thus lead to a carrying out of the analogy of the wave, the breaking of the wave, and was that the wave which such a road broke up? Or was it a movement of both—the valley moving more sluggishly, thus giving still a relative movement, leading to the ultimate breaking up of the road from the breaking of the wave?

He also wished to put to the author another point of general interest, namely, was this bituminous material useful for other purposes than road making? The author had described the bituminous elastic concrete or asphalt that he used for road surfaces, which possessed the qualities of tenacity and elasticity, which were much in request for some resilient foundation purposes, under heavily vibrating things, the chief example of which known to forgemen was perhaps found in the forge hammer. There great difficulties were experienced. Concrete was commonly used and was found too hard for the purpose in view, so timber and all sorts of ingenious arrangements were often put on top to obtain resilience. If it was not wandering too far outside the subject, he thought it would be of great interest if the author would state whether he had found other applications for the resilient concrete, as it might be called, which he had used for the road surface.

Mr. C. J. Jenkin said that he had been very much interested in the remarks that had been made in regard to the formation of waves. He had had under observation a length of road which was subject to continuous motor-omnibus traffic, and he had noticed that the waves and the valleys also were certainly advancing in the direction of the traffic; he could not say if the whole of the material in the road was moving forward, but he thought it probable that the top layer of waves was being pushed forward over the lower layer. It was only necessary to look at the road to see that the waves were curved in the direction of the traffic in the one direction, and similar waves were apparent curved in the direction of the traffic in the other direction. In both cases the waves were certainly moving forward, because if a fixed point was taken on either side of the road the movement forward was distinct. The formation of the

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waves was, he thought, particularly caused by the hammering action of the hind wheels. Water lodged in the hollows, the hind wheels forced the water into the road, with the result that valleys were formed.

He felt certain there was a certain rhythmic motion in the wheels which was no doubt largely dependent on the length of the wheel-base. If one drove over a road in a motor-car which had a smaller wheel-base than an ordinary motor-omnibus, one would be nearly thrown out of the car, whereas, strange to say, the movement was comparatively slight in the motor-omnibus which had made the waves. There seemed to be a sort of rocking motion between the vehicle and the surface something akin to cogs on wheels.

With reference to the shape of stone used, he had proved conclusively to his own satisfaction, from experiments he had carried out, that the cubical form of stone was not the best for road making under all kinds of practice. The cube lent itself to the formation of spheres sooner than any other shape of material. There was a certain amount of sliding motion between flaked stones, but there was less settlement and attrition during rolling, and with a bitumen binding they were also certainly preferable. Reference had been made to the use of slag. The reason in his opinion for the result that had been obtained from the use of that material was that slag was less elastic than granite. When two stones engaged one against the other they did not tend to roll so much; the softer material in the slag gave way and settled down to the shape of the stone next to it instead of breaking it.

The road-testing machine which had been installed at the National Physical Laboratory seemed to him an extremely interesting one, but it occurred to him to ask whether the author had made provision in the machine for a "traverse" of the wheels as they ran round on the track so as to meet actual conditions. If not, he thought that the condition which existed was very foreign to that found in actual wheels running on roads, where the traverse was even very slight from side to side.

Mr. W. Worby Beaumont said the Institution was indebted to the author for bringing the subject of road making before the notice of mechanical engineers. There was no doubt that making of roads had come into the hands of the mechanical engineers. The author had shown in his Paper some of the machinery which had become necessary in order that road making might be carried out in a mechanical way. When he said "in a mechanical way," he meant the difference between putting materials precisely where one intended them to remain, instead of merely dumping and levelling them and chancing their getting permanently into the position in which they would be most useful. He thought, however, it would be more useful if the author had said a little more, not only in regard to the construction, but in regard to the working of several of the machines to which he had directed attention, and he hoped the author would do so even in a supplemental Paper or in his reply to the discussion. A diagram was shown of the "Lightning" crusher, but very little idea was given as to how the work of that machine compared with other machines for the same purpose, and what the effect on the hinged or pivoted hammers, of working at speeds which seem to be implied, but the details of which were not given. A little further information, which the author undoubtedly possessed, might have been given in regard to the measures to be taken to secure the effective coating of whatever rock material was used as an aggregate with the best bituminous materials that could be used for the purpose. A great many difficulties were experienced in keeping the machines in order, in keeping the mixtures right and the temperatures uniform, and in getting the mixture properly delivered so that there was no segregation of the constituents of the aggregate. On the mechanical engineering side of the Paper the author had given a great deal of information, but he could give more: it was a case of "Oliver asking for more."

The author had devoted a considerable part of his Paper to the question of the corrugation of roads, on which a great deal had been said in the course of the discussion. On page 1269 a statement was made which appeared to be a contradiction, or at any rate it

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was not quite in agreement with what had previously been stated with regard to harmonic impact and the use of the three-axle roller, namely, "The chief reason why no surfaces but those of wood pavement, or of the sheet asphalt laid with a trowel and adjusted by handbeaters, are free from initial harmonic waves, is that the road-roller used when, as is usually the case, the rolling is carried out in the direction of the line of traffic, however skilful the operation of rolling is performed, always produces waves which eventually are intensified by the traffic." That was somewhat in contradiction of the passage on page 1263: "This tendency towards wave formation had already been often noticed by road surveyors, but the causes of it in the past were put down to original unequal spreading of the road material, to unskilled rolling, irregular consolidation, insufficient or irregular foundations, excessive watering, in fact to many causes other than the one now brought forward by the author. Everyone knew the roads were wavy, but no one assigned the waviness to what the author believes is the chief cause, that is, the repeated action of vehicles, closely resembling one another in their harmonic action, passing over the road at a speed sufficient to transform the smooth rolling of the wheels into bounding or pulsating motion." He thought the author was correct in his theory so far as he attributed the waviness to an origin of the rolling order in the making of the road, and the laying of the materials in rolling, or to the rolling by heavy vehicles; but when he spoke of the action as being an harmonic action at speeds sufficient to transform the smooth rolling of the wheels into bounding or pulsating motion, he thought a good deal more evidence was required of the existence of an harmonic pulsating action, and, secondly, of its effect. He was certainly of opinion that the three-axle roller described was a better implement, especially with materials the use of which the author encouraged, namely, smaller and smaller materials as the surface of the road was reached, than the ordinary brute force and heavy weight roller. No doubt if a roller had six axles and they were all very close together it might be still better for reasons which were obvious. But that there was anything like harmonic action in the ordinary traffic, either in producing corrugation or in increasing the wave height or number, was a suggestion which, in his opinion, stood in need of a good deal of further explanation and proof.

There was really no harmony whatever in his belief in the action of very variously used vehicles—vehicles with all kinds of length of wheel-base and all kinds of weight per wheel. On the other hand, engineers knew that the statement the author made on page 1269 was quite true, that surfaces which had been laid by hand, and in which no initial waves, that is, hard and soft places, had been made by rolling, did remain a long time, and perhaps continued to remain, without the formation of corrugations. The author mentioned recent roads that had been constructed with what might be called a more homogeneous metalling and surface-finishing materials, which were remaining perfectly satisfactory without corrugation. He desired to be permitted to point out that he believed he (the speaker) was the first to show in 1898, in his Presidential Address to the Society of Engineers, that in the rolling, especially of big materials, the use of which was common in 1898, the material was not only pushed forward by the rollers until it could be pushed no further, the rollers then mounting the material and crushing it down, and so producing recurrent hard and soft places, but that what the author pointed out in Fig. 4 (page 1265) actually happened. With the materials that were commonly used in 1898, and which he was sorry to say had been used for a great many years since, including the road on the Thames Embankment, attempt was made to compact lumps of granite, many of them half as big as a man's fist, into level uniformly packed masses by running a roller over them. An endeavour might just as well be made to make a level surface of the Giant's Causeway. While rolling of such materials was being done, the small materials sorted themselves out while the big materials were moving, so that there were recurrently roughly sorted large and smaller materials and hard and soft places when the roller left the road. The same thing still obtained in a modified form with more modern materials, except that the mixture of the aggregate was not affected, and it was the wave formation in the rolling process which was the origin of the

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hard and soft places which were brought out ultimately by the vehicles that ran upon the surface. If the roads could be flattened by a ramming, or punning like the ramming or flattening in a moulding box with peg and flat rammers, the corrugations would take a very long time to show themselves; but nevertheless all the materials used at the present time, especially under heavy loads with iron-tyred vehicles, must have more or less corrugations produced in them. If a perfectly homogeneous material were used, things might be altered, but so long as material of anything like a plastic nature was used, corrugations must ultimately be produced, especially in the hot part of the year, by vehicles shod with steel tyres carrying heavy loads, and giving heavy pressures per unit of area of road surface contact or bearing area.

Colonel **CROMPTON**, in reply, said that the fault of his Paper was that he had attempted to include in it material sufficient for a series of Papers. The Paper would have been advantageously confined to the one subject of the wave-formation which was observable whenever modern motor traffic became considerable. It was probable, however, that when more accurate data became available on the causes and cure of wave-formation, others would take up the subject and deal more effectively and completely with several of the questions raised by him in this Paper.

It would be convenient to take in order the remarks made by various speakers on the question of wave-formation. Mr. Beaumont (page 1308) contended that he, the author, had not proved conclusively that it was the harmonic action of motor-vehicles which was the chief cause of the wave trouble. He, however, felt certain that he could convince Mr. Beaumont that so many instances existed where the wave-formation had only appeared after the traffic had developed as harmonic traffic in the form of motor-omnibuses or motor vans, that it was only where this class of traffic formed a large percentage of the whole that the wave-formation showed itself to any marked extent. He could instance many roads, such as that from Golder's Green Station towards Hendon, Barnet to St. Albans, and half-a-dozen similar cases, where the marked wave-formation had followed very quickly on the establishment of a line of motor-omnibuses, and where such omnibus traffic practically formed 90 per cent. of the traffic traversing the road. But he agreed with him when he said that the wave-formation was in most cases initiated by the original faulty rolling. Generally, however, the waves left by the roller were long waves from two to three times the pitch of the shorter waves produced by the harmonic action of the vehicle; and undoubtedly, as Mr. Dryland and other speakers had said, there were several other causes which contributed to form the waves. For instance, any projecting lump such as a large prominence in the surface or a cast-iron surface-box covering a water-cock, was liable to start a ripple which afterwards travelled along the road in the direction of the traffic, the short waves of this ripple eventually elongating themselves into waves of a definite pitch corresponding with the traffic traversing the road.

Mr. Dryland, the County Surveyor of Surrey, who had so much to do with the reconstruction of road surfaces near to London, had had unrivalled opportunities of testing and comparing various modern systems of road surface and of judging of their respective merits, so he felt and appreciated his general agreement with him. Mr. Dryland (page 1303) agreed generally with him on the wave question and pointed out that many roads, still possessing excellent and smooth surfaces, must unfortunately be broken up and the surface re-formed solely on account of the wave nuisance. Mr. Dryland was right in saying that there was a far greater tendency to produce waved surfaces when hot material had to be rolled than was ever the case with waterbound macadam, or even with tarred slag macadam which could be rolled cold. He was undoubtedly right in this, and he, the author, had admitted it in the Paper, but engineers had to meet this difficulty of rolling hot material by some device or other which would not be so liable to form waves as the present two-axle roller. For once the hot material was finished by the roller and allowed to get cold, it set by change of state so firmly that any defects then existing would be perpetuated for long periods or until the surface could be broken up and re-formed.

(Colonel Crompton.)

In spite of these difficulties in rolling hot material, he thought it was very desirable to use it on account of its setting at once after rolling was completed; for this reason he preferred it to the rolling down of cold bituminous-bound material which, as it set slowly by the evaporation of the oils in the binder, was always, during the comparatively long period of setting, in a tender condition, and therefore at the mercy of any deforming traffic such as traction trains or heavy motor-wagons which traversed the road when it was still in this tender condition. Mr. Dryland would recollect that when one of the experimental tar-slag macadam lengths in Kingston Vale was first laid, it was deformed throughout its entire length by the passage of one traction engine with its train, and had to be re-laid in consequence. Mr. Marriott (page 1298), whose knowledge and experience of hot-rolled material was second to none, and who was responsible for the splendid surface of the Thames Embankment, appeared to agree generally as to the harmonic action of the traffic; and went further, pointing out that wave-formation extended to wood pavement and other classes of surface, although of course not to such a great extent. Mr. Marriot was doubtful whether his, the author's, proposal to use 3-axle rollers would get over the rolling difficulty. He could only point out that as far as the 3-axle system had been on trial, it had been very successful.

Mr. Mark Robinson (page 1304) generally agreed that wave-formation was caused by the traffic, but pointed out that it had been observed before modern self-propelled traffic became general. This was true, but, as he had just said, it was never so marked or so serious a question as it had become since motor-vehicles formed such a large proportion of the traffic using the roads. Mr. Massey and Mr. Jenkin both asked questions as to the forward movement of the waves. He believed there was no question that whatever was the cause when the waves were once started, they undoubtedly lengthened to some extent and that the lengthening was in the direction in which the traffic moved. They could see this in the case of waves originally in the form of a ripple which started in the wake of a projection or lump on the road surface. In this case the ripple first formed was of short pitch, but the length of its waves gradually increased until the ripple, originally of one or two short waves, gradually extended by the lengthening of these waves many yards down the road from the point where the ripple was originated.

Mr. Massey (page 1305) also called attention to the liability of the road to break up at the wave crests when the crests became pronounced. He had observed this, and believed that this breaking up of the crests determined the time at which the road surveyor must re-form the surface.

Mr. Jenkin (page 1306) appeared generally to approve of the author's theories as to wave-formation, but considered that the better interlocking of flaky-shaped stones would to some extent enable the road surface to resist the wave-forming movement. He thought, however, that Mr. Jenkin, when he said slag was less elastic than granite, would have better expressed his meaning if he had said that the slag was more *plastic* than the granite; in other words, that the roller could squeeze the lumps of slag into new forms so that the voids became better filled, and the tendency to future deformation was thus avoided.

Mr. Jenkin asked whether there was any radial traverse of the wheels used on the road machine at the National Physical Laboratory. Such end traverse was provided with the object of preventing the formation of ruts, but it had the unexpected result of producing on the test surface small geometrical marks somewhat resembling that called "engine turning" on the back of a watch.

Mr. Charles Hawksley (page 1303) called attention to a very important matter—that of the laying of pipes in carriage-ways. He thought that if there was a practice that deserved immediate suppression, it was this practice of disturbing carefully surfaced carriage-ways for pipe-laying purposes. Pipes should be relegated either to the footways or to special parts of the highway reserved for their reception. It was bad enough to break up a waterbound macadam road for pipe-laying when such a road was in good condition, but the case was infinitely worse with the modern bituminous-bound roads costing from twice to three times the

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money, and intended to last without renewal for long periods. In future roads, space for the pipe lines must be provided, either under the footpaths or wherever possible under the grass wastes at the side of the road, or in special strips separating the carriage-ways from the footways, which might be either grassed or planted with trees.

Mr. Jenkin asked whether, in the model, a sideway movement of the wheels affected the rocking action on the stones. It undoubtedly did so. Several interesting points could be observed in working the model. If the wheels were slightly skewed a lifting action on one of the wheels was observable. The Paper was, however, already too long, and it was impossible for him to go into these interesting questions.

Apart from his remarks on wave-formation, Mr. Dryland had raised a very interesting question, namely, that he thought the author's figures as to the durability of improved road-surfaces were too sanguine. He (Colonel Crompton) could not find fault with road surveyors in taking this view; in fact, they were bound to take the most conservative view when putting the matter before their Councils, but he would remind Mr. Dryland that the tarred slag laid by him near the river-front in Surbiton had been down for nine years, and had carried traffic considerably in excess of the amount of 1,000 tons a day chosen by him for his comparative Table (page 1295). If Mr. Dryland applied the figures of that Table, he would find that his (the author's) conclusions were justified, and that the saving to the users over that length of road at Surbiton in the form of reduced tyre bills, and reduced repairs following thereon, was quite as great as he had set out in the Table; so that, if he (the author) was right in thinking that the two-coat methods advocated by him would constitute a still further advance in efficiency and in reduced cost of maintenance, still better economical results would then be obtained.

Mr. Dryland had also raised another very important question, which was that in many cases the two-coat work advocated by him (the author) was unnecessary (page 1302). A large proportion of the country roads of the kingdom already possessed that, in the form of well-laid-out and well-formed waterbound macadam, the strength crust of which, if it had one wearing crust laid on it, would undoubtedly give excellent results, probably quite good enough to obtain the economical advantages he claimed in his Table.

Mr. Massey asked a question (page 1305) rather outside the scope of the Paper, on the effect of the use of bitumen for resilient foundations for machinery. He was able to state that he had had satisfactory experience with bituminous concrete used in this manner. In the course of his professional work in constructing central electric-supply stations, he had put down at Vienna massive concrete foundations insulated from the underlying earth by inserting layers of bituminous concrete, which had the effect of suppressing any vibration or preventing it from being communicated to the neighbouring premises.

Summarizing the verbal discussion, he thought that road-surfacing work was at the present time as interesting an engineering development as electrical engineering was 25 years ago, and from the nature of its problems it had attracted into its ranks and developed the electrical men of to-day. He pointed out that mechanical engineers had now before them a series of problems in machine design, and in organizing the work of road-surfacing. The urgent demand was for machinery which could be easily erected sufficiently near to the roads to be re-surfaced, which would enable the material to be crushed, dried, heated and mixed with the bituminous binders, and spread and rolled to a true surface as rapidly as possible, and with the least possible cost. Undoubtedly a chief factor which had enhanced the cost of the modern road surfaces had been the uncertainty of our climate, which saddled the road surveyor or contractor with the expense of paying a large staff of workmen and superintendents at times when the weather was so broken by spells of wet or frosty weather that actual operations of laying and rolling the material could be only carried on intermittently. The reduction of the working staff by adopting suitable machinery would therefore be attended by great economies at such times of broken weather.

(Colonel Crompton.)

He hoped he had been able to impress mechanical engineers with the nature of the problems now laid before them, and that in the design of machinery and the organization of road staff a profession was developing which afforded a fine future for the younger men.

Communications.

Professor **WILLIAM G. FEARNSIDES** (University of Sheffield) wrote that he thought a few remarks from the point of view of a geologist might not be out of place in this discussion. In a Paper which teemed with new information, the outstanding feature seemed to be the author's explanation of Road Deformation. In a general way, he thought that most people would agree that rhythmical stimulation by the repeated percussive action of similar and similarly oscillating vehicles, in that it must set up a forced vibration in the road, could do much to alter the conformation of the heterogeneous solid aggregates of which the road crust was constructed, but he did not think that evidence of such harmonic action as the whole cause of road deformation was yet before them. In discussing the movement of the stones into their new positions, the author (page 1264) found a parallel in the rocking motion of pivoted particles beneath moving wheels. He would ask how far the wood-block pavements laid on rigid concrete foundations, for example, at Hyde Park Corner or along the Fulham Road, in which rippled waviness was only too evident, could bear out the simile?

As an alternative to the author's explanation, he would suggest that the wave formation of "voidless constructions" was secondary to the lateral expansion of the crustal layers when they were compressed by passing loads or when they yielded under the percussive action of fast-moving traffic. The author found the explanation of the uniformity of wave-length of the ripples in the harmonic character of the stimulation. True, when a fast-moving vehicle got into a hole, it gave a jump and came down and knocked the road about a certain distance further on. As roads were traversed by vehicles of all sorts, weights and speeds, interference of a sort would come about and waves somewhat analagous to ocean tides might be sorted out by the harmonic synthesis which ensued. Nevertheless, on the main point he was inclined to join issue and to hold that the wave-length of the resulting folds was, in part, determined by the elastic properties of the material deformed. An unsupported cylinder of water acted upon by its own surface forces became unstable and broke into drops of equal size, and there was no doubt that a uniform sheet of road crust, held tight between its boundaries, malleable, and being rolled out under the action of traffic, must similarly become unstable and tend to break up in a rhythmic or harmonic manner. Strata in the earth's crust, where stretched, had developed joints at regular intervals and, where deformed by lateral pressure or by the shearing over them of other strata, had bent into anticlines and synclines, the wave-length of which was a function of their rigidity; and he conceived no cause why compacted superficial strata becoming folded in a road crust should invert the normal order and take the part of the bow instead of being the string of the instrument which was played upon by the traffic.

The difference between the two points of view could readily be brought to a test by measurement of the wave-length of the deformations on different sorts of road. He (the writer) was not now resident near an omnibus route, but he had notes of shallow swells on asphalt 4 feet apart, and had seen rhythmic ribs developed on soft wood pavement at intervals of less than 2 feet. In his discussion of initial harmonic waves (page 1269), the author noted how the wave-length adopted by unconsolidated material in the process of road making was greater than the wave-length developed by the trafficked road, and in this appeared the operation of a general law.

The diagrams of a new and a deformed road, Fig. 4 (page 1265), showed the accumulation of "smaller rounded stones underneath the troughs and larger stones underneath the crests of the waves,"

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but showed no polarity in the setting of the long and the short axes of the individual stones. In the development of slaty cleavage in rocks, one of the earliest results of pressure was the rotation of larger particles within the fine grained matrix and the setting of these particles with short axes parallel to and longer axes at right angles to the direction of onset of the pressure. The writer had not observed this type of polarity in water-bound macadam from which the mud matrix in wet weather was squeezed out; but, in "voidless" tar macadam taken from a well-worn road, polarity was most noticeable, and the longer axes of the stones were turned round and became sub-parallel with the road surface. It was by such internal rotation of particles, compelled by repeated impacts, each severe enough to over-pass the elastic limits of the road aggregate, that he imagined the mechanism by which the lateral expansion of the road coating must proceed.

The author mentioned (page 1265) the stones as "being propelled to new positions by the percussive action of the wheels." Did the stones move with the traffic or against it? Action and reaction were equal and opposite, and the drive of the engine should therefore pull the stones backward, whereas the braking of the load must push them onward. When the stones moved, the waves must migrate with them, and it would be of interest to learn with what velocity the wave crests advanced and how the waves produced by opposite streams of traffic interfered and behaved along the crown of the road.

Dealing with improvements of road surfaces (page 1275), the author excused the failure of tar dressing because "the action of tar does not extend sufficiently deep below the surface to hold the surface together in winter." Another way of stating this was that the break-up was due to the coming of "sub-crust dew"* which water-logged and reduced the strength of the aggregate which supported the tar and made the dressing to fail through no intrinsic weakness of its own. Asphaltic pavements (page 1276) laid upon foundations of impervious concrete were not subject to this action, for by the impermeability of the concrete the arrival of the winter's sub-crust dew was delayed or, it might be, postponed *sine die*.

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* Transactions, Surveyors' Institution, 1913, Vol. xlvi, p. 46.

Discussing the material available for double-coat work (page 1278), Colonel Crompton advocated the use of bitumen with local sand, more especially with sand artificially produced by the crushing of local rock. In this he was doubtless right, but it should be borne in mind that not all mineral particles would hold contact with pitch or bitumen under road conditions. Crushed flint seemed to the writer useless in this association, and unless "the 10 per cent. of fine limestone powder or Portland cement" (page 1279) could be persuaded to make firm junction with the quartz sand used, the bond between it and the bitumen was likely to be relaxed and the aggregate to perish as time went on. In general, the rocks most suitable for the manufacure of bituminous asphalt were the rocks with low silica percentage, and among these the igneous rocks basalt, dolerite, diorite, and gabbro must be given a high place.

In describing machinery for the laying of bituminous or pitch macadam, provision was arranged (page 1284) for fluxing the binder "to give the degree of ductility which furnishes a wearing surface of maximum strength and durability." It were well further to emphasize the importance of the latter attribute, for the "surface tension properties" of mixed tars and pitches so distributed the constituents within the aggregate that, after a time, fluxes were concentrated in the outer skin of the mass, and if those fluxes were at all volatile they evaporated away and left the ductility of the aggregate lower than it should be. In this case the brittleness was increased and its durability was quickly exhausted. With pitch aggregates spread and rolled down cold, this differential evaporation of the volatile oils of the binder was a process which was counted upon, but it was important to know and to secure that the end point of the evaporation came before the satisfactory degree of ductility had been overshot.

Although in the foregoing he had essayed a friendly criticism of some essential details of the Paper, he must confess himself in complete agreement with its main conclusions; and could not close

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without thanking Colonel Crompton for having placed so much of his unrivalled knowledge and considered judgment on matters of road construction at the disposal of a public which was ever anxious to learn.

Mr. E. **Purnell Hooley** (County Surveyor of Notts) wrote that he would like to preface his remarks by thanking Colonel Crompton for his continued "research" work—work that county surveyors and surveyors generally had no time, opportunity, nor funds to go so deeply into, as those might have, who did not come in such close contact with the money-finders, that is, the ratepayers.

The author of the Paper appeared to view the subject of roads from a standpoint which was different from that of a surveyor; the latter's livelihood and his success depended on his not being considered extravagant, wasteful, nor adding to the already overburdened ratepayer. Colonel Crompton's view seemed to point more to the fact that roads must be constructed to carry any sort of traffic, albeit that traffic might be more for the benefit of the owner of the vehicle than for the public at large. For instance, the brewer, the miller, or amusement caterer sent out his self-propelled vehicle on to the highway, and this was one of the chief road destroyers of the country roads. Did beer or bread become any cheaper by being so sent, or were the ratepayers any better for the use of steam roundabouts? These were the points that surveyors had to consider. The surveyor of the future might have different views from the present, but he (Mr. Hooley) was convinced that if Colonel Crompton were a county surveyor and had to bear the continued grumblings of added cost of roads by local ratepayers, the complaints as to the bumpy or uneven roads from those who toured in luxurious cars, and the maledictions of those who called themselves "Indignant Ratepayers" or "Farmers' Friends" in the local Press, his sympathies would be extended to the surveyors, and possibly he would see more from their point of view.

The waves in roads, in his opinion, were due to varying causes, and as yet he had never satisfied himself that any *general* cause explained the condition. The waves were caused by:—

(1) An uneven foundation;
(2) A lack of foundation;
(3) A moving sub-crust;
(4) An attempt to consolidate too great a thickness of dry material;
(5) Indiscriminate mixing of varying gauges; and,
(6) Steam-rolling longitudinally.

Causes 1 and 2 were practically impossible to avoid, unless funds could be provided to remake the roads entirely. Cause No. 3 could be avoided to a great extent by using more "sticky" material, and the careful filling of "dry" material to prevent voids. Causes 4 and 5 could be absolutely remedied if material.were laid each in the various gauges and the voids filled up in the lower before the application of the wearing face, the voids of which must also be filled. With regard to cause No. 6, he was of opinion that if a roller could be designed to work at an angle *across* the natural course of traffic, a great improvement would result in the ever-present "waves." From the writer's own observation, he had seen far more waviness in some of the most heavily trafficked streets of London where asphalt was laid, than he had *proportionately* on county roads, and he could only imagine that Colonel Crompton had either missed those streets, or he (Mr. Hooley) had looked at the streets from a different view.

The question of original cost for treatment of roads again arose here. He was convinced that few County Councils in the United Kingdom would care to risk the cost of asphalt road construction at, say, 15*s.* per yard, even if it could be proved that the life would be fifteen years, if they could obtain a road costing 3*s.* per yard to construct, if it would last seven years.

He awaited with interest the result of the trials of three-axle rollers; but here again it was impossible for county surveyors to experiment. They had no funds and their Councils had no funds for experimental purposes. If the author could by any means solve the difficulties of setting Councils up in funds for "experiments," he was sure there were young surveyors able and willing to give their personal services. He (the writer) had endeavoured to

(Mr. E. Purnell Hooley.)

advance the "Good Roads" movement, and was gratified to find that Colonel Crompton had personally given him credit for the little he had done.

Mr. J. S. **Killick** (Assistant Engineer, The Road Board) wrote that it was difficult to believe that the damage done by a ton carried on steel tyres was not more than half as much again as that done by a ton carried on rubber tyres.

The Table (page 1295), showing how running costs were reduced by road reconstruction on one mile of road carrying 1,000 tons per day, appeared to be not so much a Table showing how running costs could be reduced as one showing that a well-surfaced road could be maintained at the same cost as an ordinary road surfaced with waterbound material, with the additional advantage that the running cost per mile per vehicle was less. He had no doubt that the figure given as the running cost per vehicle-mile was correct, as it was obvious that wear and tear and fuel consumption must be less on the better surface in proportion to the reduction in tractive effort required on it.

With regard to the cost of reconstructing a road in double coated work, he inferred that Colonel Crompton had in his mind double-coated asphalt macadam, and the following remarks were based on this assumption. He submitted that the initial cost was very much underestimated, for he found, on making inquiries, that the price quoted in the London district for double-coated asphalt macadam with twelve years' maintenance was 11*s.* to 12*s.* per super yard, and 9*s.* 6*d.* to 10*s.* 6*d.* per super yard in a neighbourhood where good stone was available locally. This was equivalent, on an 18-foot road, to £6,072 and £5,280 per mile respectively, or with a life of twelve years, was equal to £506 and £440 respectively, an increase of £206 and £140 per mile per annum.

These figures not only showed that the cost per vehicle-mile for road maintenance was more than on an ordinary road, but they would lead one to think that such a class of surfacing was extravagant, and not warranted by the traffic the road was called upon to bear.

The foregoing figures made the following alterations necessary:—

Costs as they would be.

Vehicle.		Road.	
£	Per Vehicle-Mile.	£	Per Vehicle-Mile.
4,280	7·5*d*.	303	0·531*d*.
1,200	12·0*d*.	203	2·300*d*.

Mr. **Francis Wood** (Borough Engineer and Surveyor of Fulham) wrote that he was inclined to disagree with the contention as to the deformation of the road by a rhythmic action of the wheels. As it was not explained how this rhythmic action was generated, it must be assumed that the author had some doubt on the point himself. In the writer's opinion, the wave formation was caused by the body or load of the vehicle falling into a depression, and the spring attached to the wheel, having received a shock greater than the normal load, took it up, and in the reflex action a decreasing excess weight above the normal of the vehicle came down on the road structure at certain intervals depending on the spring until it assumed a normal position again.

If an ordinary spring-balance were taken, and a specified weight was allowed to fall, say, ¼ inch on to the scale, the register indicated about twice the dead weight; if it fell ½ inch the register indicated three or four times the dead weight; consequently, if a similar action were in operation by means of a load dropping on to the springs attached to the vehicle, one could easily understand how the structure was affected detrimentally. If, however, it was due to the harmonic action of the wheel, and had no reference to the springing of the vehicle, then in a composition which was capable of being affected, one would assume that throughout the length of road in which that composition was laid the waves would be regular and apparent, but this was not the case.

In the writer's district a section of road was laid at the commencement of which were two rows of sett paving laid on

(Mr. Francis Wood.)

concrete, and therefore non-compressible; the material forming the section was a compressible bituminous substance. The vehicles which were constantly traversing the road were of a commercial type; immediately beyond the sett paving a hollow began to appear, and after a few months a second hollow developed 4 feet away, but immediately following there was only a slight development, and then the surface remained approximately as it was originally laid. The first hollow became so deep that it had to be repaired. On wood pavement—as another example—the road (Fulham Road) was subjected to a continuous run of motor-omnibuses. The pavement where it was straight on either side of the curve was comparatively free from observable waves, but as it approached the curve round a refuge, the waves were distinct; the first approximated to the beginning of the curve, the second was 4 feet 3 inches away, the third was a similar distance, the fourth was 3 feet, and then there were a number which were about 1 foot 3 inches away from each other; all these were on the offside of the vehicle, and none was distinctly observable on the near-side track. This indicated that the weight of the vehicle was thrown on to the offside in the direction of the centre of the curve, and the spring action was reflected on the paving.

Similarly, on macadam roads the first hollows were 5 to 6 feet apart, and, as they developed, new hollows became apparent between the first two until there was a sequence, but the hollows all varied in depth, the first being the deepest. Where motor-omnibuses had run on macadam roads, a similar action was developed, but at a very much quicker rate.

In wood paving there was a forward thrust in evidence, which was seen on those pavements especially where there had been no adhesive substance applied between the blocks and the concrete on which the blocks were laid, and the original line of the blocks being diverted into an S-curve, the two apexes of the curves being in the direction of the traffic, the camber of the curve being at most 6 inches, but where there was adhesion this curvature was not so noticeable, and therefore indicated that the push was not of very serious moment, and could be overcome by the use of a proper consistency of cohesive material.

In all forms of *in situ* pavements there were bound to be defects, and, in bituminously formed materials compressed by a roller of whatever characteristics, those defects would not be overcome. The material should be laid at a perfectly even temperature, and under exactly the same conditions, but each load varied in temperature in some degree; the outside and more exposed material suffered from radiation, and the length of time before the roller was brought on to the material varied very considerably. The human element and the atmospheric elements had to be allowed for, consequently compression varied throughout the whole length of the road, but the writer had not found that any serious defects were developed by the method of rolling that he adopted. As far as possible, the material was pushed into position by the men in laying the composition, and compression was secured in this manner; the rolling was of such a character that it merely gave a surface compression with a weight not exceeding 120 lb. per inch of roller-width, followed after only one motion forward and backward by a weight not exceeding 240 lb. per square inch. Too much rolling, in the writer's opinion, reduced the life of the composition, a voidless structure being undesirable in the road surface. He relied on the ductility and cohesiveness of the bitumen employed in the structure for the prevention of the "push-forward," which he had indicated was not of a serious character, and he considered that if the bitumen was suitably tempered the small irregularities in the surface, due to unequal compression, were not increased to any considerable extent under hot atmospheric and traffic conditions. He did not consider that there was any push forward to the ordinary macadam; that there was a curve in direction of the traffic was due to the manner in which the traffic came into the hollow or depression; where the curve was greatest, it was there where it was most affected and the disintegration was severest; but he had had no example where macadam properly settled into position had been pushed forward, otherwise the general level of the road would have been very high in places, whereas the general level was maintained.

He had noticed a distinct push forward in those compositions where the material had lost a considerable proportion of its ductile

(Mr. Francis Wood.)

or cohesive properties, for example, where tar was used on variously graded aggregates, and which was softened considerably in hot weather, or in bituminous compositions similarly affected by hot atmospheric conditions, but it was not so noticeable in the asphalt macadam roads where large stone was employed, nor in the bituminous surface mixtures on a tarred concrete (old macadam) base, in which the bitumen had been suitably tempered. The writer had devised a stone drier which was working very satisfactorily at his depot, and he would be very pleased to demonstrate its usefulness to Colonel Crompton and others who might be interested in the subject.

Colonel CROMPTON, in reply to the written Communications received since the Paper was read, had carefully studied Mr. Hooley's views (page 1320). He hoped that nothing in the Paper would bear the construction put on it by Mr. Hooley that he (the author) animadverted in any way on the work of the existing road surveyors. Far from it; no one had greater sympathy with their difficulties than he had. His Paper was intended for them to study and to take from it anything they found useful and which would help them with the difficult problems they had now to encounter. He was glad to find that Mr. Hooley's six causes for wave-formation really coincided with his own, the only difference being that Mr. Hooley laid great stress on causes 1 to 4, whereas he, the author, had laid greater stress on 5 and 6. He wished to avoid the indiscriminate mixture of gauges by using the two-coat arrangement, in which the fine material was all close to the surface. Although Mr. Hooley put No. 6—steam-rolling longitudinally—as the last, he thought that if Mr. Hooley had had similar experience to his own in the roads near and about London, he would have come to the same conclusion as himself as to the preponderating importance of this last cause of wave-formation.

To Mr. Hooley must be given the credit of having introduced the use of tar-slag macadam, a material which, in the author's opinion, was the easiest of all the modern waterproof materials to roll in its cold state to a very satisfactory surface, and it suffered surprisingly little from the deformation of heavy traffic. Having so great experience in the use of this class of material, and not having had any considerable harmonic traffic over these roads, Mr. Hooley naturally did not attach such importance to the wave question as he did, but he felt that Mr. Hooley was likely to have eventually the same opinions that he himself held. In his spoken reply to others he had mentioned how very perfectly tar-slag macadam had its voids filled on account of its somewhat plastic nature under the roller.

To one remark of Mr. Hooley's and to Mr. Killick (page 1322) he must demur, and that is, that it was necessary to spend such large sums, such as from 11*s*. to 15*s*. a superficial yard, to obtain the asphaltic surfaces from which he, the author, believed such great economies would accrue to the owners of the roads. To both these gentlemen he would point out that, as Mr. Dryland had shown, a great mileage of the roads of the kingdom was already in such good condition that the existing macadam surface could be utilized as a supporting crust, and that all that was necessary was to add a well-made wearing crust of the nature advocated by him, by Mr. Marriott and others, which was, one composed of fine material cemented and held together by bitumen. If the cost of doing this work were substituted for the cost of the double-coat work he had given in the Table (page 1295), it would be found that all the savings that he suggested as likely to accrue to the owners of vehicles were obtainable, and that the maintenance cost he had laid down would be obtained without difficulty.

He had read with much interest Mr. Francis Wood's views as to the cause of deformation of road surfaces (page 1323). His answer to Mr. Wood was that this wave-deformation had to be accounted for. Mr. Wood had experienced it himself on the experimental lengths he had laid down in Fulham, and had particularly noticed wave-formation at points originated by the two rows of setts he had introduced to separate each experimental section from the adjoining section. Mr. Wood practically corroborated all that he (the author) had stated as to the waves being originated by any projection such as these dividing setts. Mr. Wood, in common with Mr. Robinson and others, had noticed that wave-formation was not confined either to macadam or to asphaltic surfaces, but occurred to a limited extent with wood pavement, and he also had made valuable detailed observations as to the shape and direction taken by the waves formed. Mr. Wood and Mr. Marriott were both of opinion that a voidless supporting crust was undesirable. In this they were at variance with the author and with many of the speakers who believed that the best method to resist wave-deformation was by making the supporting crust as immovable as possible by making it voidless. Mr. Hooley in particular, whose system had most successfully resisted waves, was very strong on this point. The question was still open. Mr. Wood and Mr. Marriott seemed to think that if a certain proportion of voids were left in the supporting crust when it was first made, that the traffic would of itself reduce any original waves left by the rolling by the automatic elastic action of the voids in the subcrust. Time would show which of the two schools of thought was right in this important question. A set of experiments was about to be carried out with the road machine at the National Physical Laboratory which would go far to settle the question. Although he differed from Mr. Wood on this one point, he was in agreement with him on many other of his observations which threw further light on this important question.

Mr. F. E. Powell, of Auckland, N.Z., wrote * that motor traffic in New Zealand was not yet of sufficient volume to affect their road surfaces in the manner pointed out by the author, but he thought that climatic conditions on the whole were the most destructive agents to roads which had been constructed on faulty principles. The indiscriminate and improper use of boulders as a foundation for new road construction in a heavy-clay country should be deprecated.

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* Received on going to press. [Secretary, I.Mech.E.]

MEMOIRS.

Sir William Henry Bailey was born at Salford on 10th May 1838, and attended the Manchester Grammar School until he was 14 years of age. On leaving school he entered the Albion Works, which had been established in 1838 by his father—Mr. John Bailey—in Oldfield Road, Salford, on the site of the present large works of Sir W. H. Bailey and Co., Ltd. In 1866 he became proprietor and sole manager of the concern. He entered the Salford Town Council in 1874, was elected an alderman in 1880 and Mayor of the borough in 1893. He was knighted by Queen Victoria on the royal yacht in 1894 on the occasion of Her Majesty opening the Manchester Ship Canal. Sir William was one of the promoters of the Manchester Ship Canal, and was a member of the Provisional Committee, having taken part in the famous "round table" conference at The Oaks, Didsbury, the residence of the late Mr. Daniel Adamson. He was one of the directors at the formation of the Ship Canal, and at the time of his death was the only member of the present Board who had been connected with it from the commencement. He was a Justice of the Peace for the County of Lancaster and also for the County Borough of Salford.

Sir William was at one time or another the President of various Societies, notably, The Library Association of the United Kingdom, the Manchester Literary and Philosophical Society, The Manchester Reform Club, The Manchester Association of Engineers, The Manchester Shakespeare Society, The Manchester Dickens Fellowship, the Manchester Field Naturalists' and Archaeologists' Society, besides being President and Vice-President of a large number of Art, Literary and Social Societies throughout the North of England. At the time of his death he was a Fellow of the Royal Geographical Society, a Governor of the John Rylands Library, and a Governor of the University College of Wales, Aberystwyth. In 1905 he designed and presented a mace to the Victoria University of Manchester. In order to perpetuate the memory of Dr. James Prescott Joule, the discoverer of the Mechanical Equivalent of Heat, and who was a native of Salford, Sir William deposited with the Treasurer of the County Borough of Salford a sum of money to provide a silver medal annually to be known as the "James Prescott Joule Commemorative Medal," for the students of Salford and Manchester and the Institution of Civil Engineers for the best essay on Physical Science or Engineering, preference being given to the Paper dealing with the transformation of energy.

Sir William was an old Volunteer, and he assisted to form No. 3 Company of the 56th Lancashire Volunteers, which afterwards became the 3rd V.B. Fusiliers. He served a good many years in the Battalion, and had always been a strong supporter of the Territorial Force. He was a member of the National Reserve. Apart from his active business and public life he found time to write a large number of books and to deliver lectures on various subjects. In collaboration with Professor Tyndall, Sir William carried out a number of experiments on Sound at various south coast ports with the object of giving a plainer and clearer language to mariners and lighthouse keepers. He strove to induce the Government to adopt the Morse Code as the alphabet of the sea, so that ships could by day or night, in fog or storm, communicate with each other, avoid collision, exchange news and give readier help in shipwreck and disaster. He was responsible for many inventions, and, together with other members of the family, was identified with nearly one hundred specifications during the period 1857 to 1912. His death took place suddenly at the Savoy Hotel, London, on the 22nd November 1913, at the age of seventy-five. He was elected a Member of this Institution in 1885; and he was also a Member of the Iron and Steel Institute.

JOHN ORME BRETTELL was born at Dudley on 16th September 1866. He was educated at the Royal Orphanage, Wolverhampton, and then from 1881 to 1884 served an apprenticeship with Messrs.

J. O. and C. E. Brettell, general engineers, of Worcester. During the latter period he attended evening classes at the Worcester School of Art. He then joined the drawing office staff of Messrs. McKenzie and Holland, railway signal engineers, Vulcan Iron Works, Worcester, in whose service he remained for nearly thirty years as draughtsman, and finally chief draughtsman of the Worcester office, which position he held up to the time of his death. During that time he was responsible for the design of many of the interlocking systems installed on the leading railways. For over twenty years he served in the Volunteer Artillery, and rose to be Brigade Quartermaster Sergeant. His death took place, after some months' illness, on 11th September 1913, in his forty-seventh year. He was elected an Associate Member of this Institution in 1908.

William Henry Cave was born at Dover on 30th September 1863. He was educated at Providence, Rhode Island, U.S.A., and subsequently at the Bolton Grammar School, the Church Institute, and the Mechanics' Institute, Bolton. In 1881 he began an apprenticeship of four years with Messrs. Hick, Hargreaves and Co., engineers, of Bolton, and on its completion remained with the firm until 1887, when he was appointed to take charge of the Springfield Paper Mills, Bolton. Three years later he became superintendent engineer to Messrs. G. Knowles and Sons, Peel Mills, Bolton, in whose employ he remained until 1893, when he went to Russia as chief engineer to the Pereslavlsky Manufactory, Pereslavl, a firm employing 3,000 hands. He remained in that position for nine years, and returned to England in 1902. In the following year he was engaged as superintendent engineer at Messrs. Clark and Co.'s Anchor Thread Mills, Paisley, where he supervised the carrying out of many of his own inventions. His inventions, some of which were carried out when he was in Russia, comprised improvements to water-gauge fixings, forced draught for furnaces, textile machinery, etc. His death took place at his residence in Paisley on 12th October 1913, at the age of fifty. He was elected an Associate Member of this Institution in 1903.

OSBERT CHADWICK, C.M.G., was born in 1844, being the son of the late Sir Edwin Chadwick, K.C.B. After studying at the Royal Military Academy, Woolwich, he obtained a Commission in the Royal Engineers in 1864. Four years later he went to India, and was attached to the Public Works Department. In this capacity he had charge of the workshops and the management of a flotilla of barges used at Bombay in connection with reclamation work. In 1871 he was transferred to Aden and was engaged in erecting machinery for a steam flour-mill and bakery. He left the service in 1873, and was appointed engineer to the Odessa Water Works. Subsequently he acted in the capacity of consulting engineer to the Colonial Office, mainly in regard to sanitary work for the Crown Colonies, and spent many years in Grenada, Hong Kong, Mauritius, and other colonies. He also constructed the Malta Water Works, and for his services in this connection he was made a Companion of the Order of St. Michael and St. George in 1886.. His death took place at Knocknalling, Kirkcudbrightshire, on 27th September 1913, at the age of sixty-nine. He was elected a Member of this Institution in 1892; and he was also a Member of the Institution of Civil Engineers.

EDMUND BARROW CHITTENDEN was born at Haywards Heath on 19th August 1854, being the second son of the late Andrew Chittenden, of Maidstone. He was educated at Sutton Valence School, near Maidstone, and by a private tutor. Then for a short time he went to the Engine and Locomotive Works of Messrs. Robert Stephenson and Co., Newcastle-on-Tyne, where, meeting with a severe accident to his hand, he was temporarily incapacitated, and returned to Kent. He next became articled to Messrs. Aveling and Porter, of Rochester, and went through all the shops. In 1875 he joined his father, and shortly afterwards became partner in the firm of Chittenden, Knight and Co., at that time one of the largest owners of steam ploughing and threshing machinery, in the Kingdom. To this business he brought industry, ability, and integrity, whilst his special knowledge of this machinery, acquired in the Rochester Works, made him of great use in administering the details of a complicated business and in maintaining the machinery in efficient repair. The ploughing business was very successful, until the general depression in agriculture largely reduced the area of arable land. About this time the firm added steam-rolling to their other operations, which brought Mr. Chittenden in contact with most of the public bodies of Kent. Having taken into partnership Mr. Percy A. Simmons, the firm still further developed their road-contracting business, and purchased some quarries. In 1906 the business was converted into a limited company, with head offices in Maidstone, and carried out large contracts for tar macadam and bituminous road surfaces for the Kent County Council, the London County Council, and other public bodies. For twenty years Mr. Chittenden was Honorary Secretary of the Kent Engine Users' Association, and for many years he was Chairman of the National Traction Engine Owners' and Users' Association, and a director of Messrs. Aveling and Porter. He was one of the earliest locomobile owners in 1900. In June 1913, while being driven in a small car on the main road out of Maidstone, he was run into by a large car which was crossing from a by-road, and was terribly injured. Although it was hoped that he might recover, his death took place at his residence at West Malling, on 14th July 1913, in his fifty-ninth year. He was a Member of this Institution from 1886 to 1891, and from 1895 to the time of his death; and he was also a Member of the Royal Agricultural Society.

ROBERT DAVISON was born in Glasgow on 3rd June 1848. He was educated in his native city, and served his apprenticeship with Messrs. Neilson and Co., locomotive builders (late Messrs. Neilson, Reid and Co., and subsequently part of the North British Locomotive Co.). On the completion of his apprenticeship in 1869 he joined the Yorkshire Engine Co. as foreman of the Fitting Department. Ten years later he became foreman of the Machine Shop at the Cowlairs Works of the North British Railway Co., under the late Mr. Dugald Drummond. Remaining there until 1882, he joined the Caledonian Railway Co. as superintendent of the Machine and Fitting Departments at their St. Rollox Works. While he was there the works were entirely rebuilt, and the machine shop re-arranged to facilitate rapid production, and many improvements in detail were inaugurated as a result of his wide experience. He retained this position until his death, which took place in Glasgow on 22nd September 1913, at the age of sixty-five. He was elected a Member of this Institution in 1884; and he was a Member of the Glasgow and West of Scotland Foremen Engineers Society, of which he was President in 1901-2.

HERBERT WILLIAM GARRATT was born in London on 8th June 1864. After being educated at various private schools in London, he served an apprenticeship from 1879 to 1882 in the locomotive works of the North London Railway at Bow. On its completion, he went to the marine works of Messrs. W. Doxford, Sunderland, and remained there until 1885, when he became locomotive inspector for Sir Douglas Fox. In the following year he transferred his services to Sir Alexander M. Rendel, for whom he acted as inspector of permanent-way materials for two years. In May 1889 he was appointed head draughtsman on the Central Argentine Railway, having charge of the installation of the vacuum brake to the rolling-stock, and of Pintsch's system of gas lighting to the carriages and workship. Three years later he became locomotive superintendent of the same railway, which post he held until 1900, when he was appointed locomotive, carriage, and wagon superintendent of the Cuban Central Railways, and in the following year he became locomotive superintendent of the Lagos Government Railways. In 1904 he was appointed to a similar position on the Lima Railway in Peru, on which line he introduced a system of liquid-fuel burning for locomotives. When this line was taken over by an electric company in 1906, he returned to England. Here he was engaged in the inspection of the building of locomotives. Finally, he introduced the well-known type of engine bearing his name, an illustration of which was given in the Institution Proceedings for 1912 (Fig. 62, Plate 26). His death took place at Richmond, Surrey, on 25th September 1913, at the age of forty-nine. He was elected a Member of this Institution in 1902.

Malcolm Howie was born in Manchester on 30th July 1877. He was educated at the Manchester Central Board School and the Municipal Technical School. In 1895 he began an apprenticeship of five years, the first two years being served with Messrs. George Birch and Co., machine-tool makers, of Sheffield. Two years were next served in the drawing-office of Messrs. Dorman and Smith, of Salford, and the remaining one year with the Edison, Swan Co., of Broadheath, Manchester. In 1900 he went to the United States, and was employed by the Jones and Lamson Machine Co., of Springfield, Vermont, in installing their machines in America and England. This position he held until 1905, when he transferred his services to the Fellows Gear Shaper Co., of Springfield, Vermont, and represented this firm in England and on the Continent until the time of his death, which took place at Manchester on 16th April 1913, in his thirty-sixth year. He was elected an Associate Member of this Institution in 1906.

Piroshaw Bomanjee Jeejeebhoy was born at Bombay on 19th December 1856, being descended from the Jeejeebhoy Dadabhoy family, one of the oldest Parsee families. He was educated at the Proprietary High School of Bombay, and was one of the few students that matriculated in English. Being of a mechanical turn of mind, he became an apprentice in the weaving department of the Great Eastern Spinning and Weaving Mills Co., at the age of sixteen. The mill industry of India at that time was in its infancy, and Bombay was the only place that contained a few mills of a modern type. On the completion of his apprenticeship, he was appointed in 1877 head of the weaving department of the Mazagon Spinning and Weaving Mills, and several looms were erected and started under his supervision. Six years later he resigned this position to superintend the erection of the Gordon Spinning and Weaving Mills Co., and subsequently was apprenticed in the same mills in the carding and spinning departments. He also supervised the erection of the greater part of the machinery in these mills. Having obtained a thorough knowledge of the carding, spinning, and weaving departments of the mill industry, he determined to study the engineering department; and as there were no suitable engineering works in India, he came to England, where he studied as an apprentice for five years at Messrs. Hick, Hargreaves and Co.'s Soho Iron Works, Bolton. Having returned to Bombay with a First Class Engineer's Certificate, he was at once appointed manager of the Sassoon Spinning and Weaving Mills Co., which he brought to a high state of efficiency. In 1896 he resigned his post, and became manager of both the Mazagon Spinning and Weaving Mills Co. and the Framji Petit Spinning and Weaving Mills Co. Such was the demand for his services that, immediately after his appointment, he was offered a high post in the Excise Department, which however he declined. In 1903 he retired from business. Soon after he gradually became ill, and underwent two operations for cancer, but his death ensued on 6th August 1913, in his fifty-seventh year, at his residence in Bombay. He was elected a Member of this Institution in 1888.

WILLIAM WARNER JUDD was born at Leicester on 11th February 1861. He was educated at the Leicester Grammar School from 1874 to 1880, and also received private tuition in technical subjects. In 1880 he was apprenticed to Messrs. J. Jessop and Son, London Steam Crane Works, Leicester, and passed through the various shops and the drawing office. On the completion of his apprenticeship in 1885, he worked as a draughtsman in the firm's London office until 1887, when he was employed by Messrs. Death and Ellwood, Leicester, in a similar capacity. Five years later he became manager to Messrs. J. S. Haswell and Co., of the same town, and in 1897 Messrs. A. Barron and Co., Leicester, appointed him their chief draughtsman. After two years in this position, he went to Holland as works manager at the Alkmaar Iron foundry, where he also supervised the erection of their gas- and oil-engines. In 1904 he was appointed by Messrs. Davey, Paxman and Co., of Colchester, as head of their gas- and oil-engine department, and this position he held until his death, which took place on 3rd November 1913, in his fifty-third year. He was elected a Member of this Institution in 1911.

William Mallet Kent was born in Liverpool on 11th July 1878. He was educated locally at the Marlborough College, and afterwards at the Liverpool College. On leaving school in 1894 he was apprenticed to Messrs. Fawcett, Preston and Co., of Liverpool, and at the conclusion of his service in 1900 he joined the Stott Line of steamers as junior engineer, and remained in that employ until he obtained his Chief Engineer's certificate in 1904. He then transferred his services to the Coker Line for a short time, after which he was engaged by the Moss Line, trading to Mediterranean ports. In 1909 he was appointed assistant engineer in the Public Works Department of Cyprus, and soon became associated with the various schemes for the betterment of that island. His zeal and devotion to his work hastened his death at Nicosia, which followed from an attack of pneumonia, on 31st August 1913, at the age of thirty-five. He was elected an Associate Member of this Institution in 1912.

Sir William Henry Preece, K.C.B., was born at Carnarvon on 15th February 1834. He was educated at King's College School, London, and at King's College; he also attended the lectures of Michael Faraday on Electricity, at the Royal Institution. On leaving College he entered the office of the late Mr. Edwin Clark, where he studied for some little time. In 1853 he entered the service of the Electric and International Telegraph Co., and three years later he was appointed superintendent of the southern district of this company. At the age of twenty-four he was also given the appointment of engineer to the Channel Islands Telegraph Co. In 1870, when the Government bought up the telegraphs, he was transferred to the Post Office as Divisional Engineer, becoming successively Electrician in 1877 and Engineer-in-Chief in 1892. On his retirement, under the age rule, in 1899, he was appointed Consulting Engineer to the Post Office; this connexion terminated in 1904. Thereafter he practised as consulting engineer in Westminster, in partnership with the late Major Cardew, his two sons, and others.

Sir William Preece's name is associated with many improvements and inventions in telegraph work. At the age of twenty-one he brought out a system of duplex telegraphy, and between 1862 and 1873 he turned his attention to railway signalling apparatus. His other inventions relate directly to telegraph apparatus. He introduced the use of electric bells in 1865. He devised a new method of terminating wires in 1858, a new telephone in 1878, having brought over to this country the first practical telephone in 1877, and in 1892 originated a system of signalling across space by induction telegraphy. When Mr. Marconi came to England in 1896 he found a warm supporter in Mr. Preece. He improved the overland lines, which suffered severely from the weather, and began to lay down trunk telephone lines, which his successor, Sir John Gavey, took up and carried through. In collaboration with other scientists he published several practical text-books. In 1877 he went to America on behalf of the Government to study telegraphy as practised in the States, and he visited various foreign countries, frequently in his official capacity as a member of conferences or of exhibition committees. He was a member of the Royal Commission on Electrical Communication with Lighthouses and Lightships, which sat from 1892–7, and he was one of the six original founders of the British Fire-Prevention Committee. Sir William was an active member and supporter of the Engineering Standards Committee, and on the formation of the Electrical Section he was appointed Chairman of that section. He was elected a Member of this Institution in 1890, and was President of the Institution of Civil Engineers in 1898. Of the Institution of Electrical Engineers he was President in 1893, which was really his second term of office, since he had been President of the Society of Telegraph Engineers in 1880. The Royal Society elected him a Fellow in 1881, and at the Paris Exhibition of 1889 he was appointed an Officer of the Legion of Honour. He was created a Companion of the Order of the Bath in 1894, and promoted to be K.C.B. in 1899 on leaving the Post Office, as a recognition of his services to that Department. Two years ago, when his strength was failing, he went back to his native town of Carnarvon, where his death took place on 6th November 1913, in his eightieth year.

THOMAS EBENEZER PYE was born at Chester on 16th March 1862. He was educated at the Middle Class School, Chester, and served a pupilage of seven years, from 1879 to 1886, with Mr. Fletcher W. Stevenson, Engineer and Manager of the Chester Gas Works. In 1886 he left Chester to take the supervision of the western district of the Commercial Gas Co., London, and held the position until 1891, when he became assistant engineer and manager of the Shrewsbury Gas Co. In 1895 he resigned his post and practised principally as lighting engineer in London and the Provinces. After being abroad for a short time, he obtained the appointment of engineer to the Sandwich Gas Co. Early in 1905 he was selected to succeed Mr. R. S. Church as engineer and manager of the City of Chichester Gas Co.; and under his supervision the works were reconstructed. His death took place in London on 15th October 1913, at the age of fifty-one. He was elected an Associate Member of this Institution in 1906; he was also a Fellow of the Chemical Society.

HENRY PERCIVAL RILEY was born at Swindon on 9th January 1877. He was educated at Swindon High School from 1889 to 1894, and attended evening classes at the Swindon and North Wilts Technical School during his apprenticeship, which was served from 1895 to 1899 in the locomotive works of the Great Western Railway at Swindon. On the completion of his apprenticeship, he entered the marine department of the Great Western Railway and served for six months as 3rd Engineer on the S.S. "Ibex." He next made voyages on a tramp steamer, and then in 1901 entered the service of the P. and O. Steam Navigation Co., spending nearly two years on S.S. "Arabia," as assistant engineer, after which he obtained the 2nd Engineer's Board of Trade Certificate. On leaving the service at the end of 1901 he was engaged in the running department of the Great Central Railway, and was subsequently made foreman of the Running Sheds. In 1905 he went out to Cuba to take up the position as draughtsman on the Cuban Central Railway, and in May of the following year he was appointed chief carriage and wagon foreman at the Cardenas Works of the United Railways of Havana. Two years later he was promoted to be assistant locomotive superintendent of a division, and on the erection of new locomotive workshops in Havana in October 1909, he was appointed works manager. In 1911 he resigned, to enter the service of the Central Argentine Railway, Argentine Republic, as Chief of the Locomotive, Water Supply, and Vehicle Revision Section, and continued in that position until July 1912, when he was appointed Running Superintendent of the Rosario District. His death took place from peritonitis on 14th November 1912, in his thirty-sixth year. He was elected an Associate Member of this Institution in 1911.

CHRISTER PETER SANDBERG was born at Venersborg, Sweden, on 8th October 1832. After completing his technical education, he was employed at various blast-furnaces and ironworks in his native country, and in 1855 he received a premium from the Swedish Iron and Steel Association to enable him to pursue still further his practical study in iron manufacture. In 1860 he came to England on behalf of the Swedish Government as inspecting engineer for rails intended for the Swedish Railways, and held this position until the time of his death. In 1862 he was sent by the Swedish Iron and Steel Association to Spain, Italy, and Austria, to study and report upon the iron industries of these countries. In 1868 he also established a general consulting practice for permanent-way material, and soon acquired a world-wide reputation on this subject. For many years he had been consulting and inspecting engineer to the Swedish, Chinese, and Siamese Governments, and during this period he read a number of Papers before British and American Institutions. In 1890 he contributed a Paper to this Institution on "Steel Rails, considered Chemically and Mechanically." His sections of rails, known as the Sandberg sections, were first brought out in 1878, and a later design in 1894. For his services in regard to railways he received decorations from his native country, from France, Belgium, Russia and China. His death took place, after a short illness, at his residence in Sydenham, London, on 4th December 1913, at the age of eighty-one. He was elected a Member of this Institution in 1890. He was also a Member of the Institution of Civil Engineers, of the Iron and Steel Institute, and of the Société des Ingénieurs Civils de France.

JOHN HUTCHINSON SHARP was born at Farndon, Buckinghamshire, on 15th July 1860, being the eldest son of the late Rev. John Prior Sharp, of Longstowe, Cambridgeshire, and grandson of John Sharp, one of the founders of the firm of Messrs. Sharp, Stewart and Co., Atlas Works, Manchester. He was educated at Uppingham School, and afterwards served an apprenticeship at the Atlas Works, with which establishment he continued to be associated throughout his career. Shortly after the completion of his apprenticeship he was appointed assistant works manager, a position he held until the removal of the firm to Glasgow in 1888, on the expiration of the firm's lease of the Atlas Works, Manchester, when the works of the Clyde Locomotive Company at Springburn were acquired, and which have since been known as the Atlas Works, Glasgow. He took up his duties in Glasgow as the assistant to the Managing Director of the firm, and in this capacity he paid several business visits to Brazil and other places abroad. In 1903, when the North British Locomotive Co., Ltd., was formed by the amalgamation of the three locomotive building establishments in Glasgow, he was appointed Managing Director of the Atlas Works, a position he held until his death. In all matters pertaining to locomotive design and construction he displayed a keen and enthusiastic interest, being specially alive to all the recent developments in this important branch of engineering. His death took place after a brief illness at his residence in Glasgow on 6th November 1913, at the age of fifty-three. He was elected a Member of this Institution in 1895.

MAXIMILIAN RICHARD WESTERN was born in London on 25th May 1850. He served his apprenticeship at the Locomotive Works of the London, Brighton and South Coast Railway at Brighton, under the late Mr. William Stroudley. Subsequently he entered into partnership with Messrs. Powis, James and Co., Ltd., engineers, of Lambeth. In 1882 he joined the service of the Bombay Burmah Trading Corporation, Ltd., Rangoon, where he also held the position of Government Inspector and Chairman of the Board of Examining Engineers under the Burmah Boilers and Prime Movers Act, 1882, and for several years he was engineer and manager for this Corporation in Bangkok, Siam. On returning from the East in 1894 he entered the office of the Inspecting Engineer to the Egyptian and Sudan Governments in London, where he remained until his death, which took place in London on 2nd October 1913, at the age of sixty-three. He was elected a Member of this Institution in 1877.

ARTHUR DOUGHTON WILLIAMS was born at Aberystwyth on 26th January 1885. His education was received at local schools and at the University College of Wales from 1898 to 1900. During the latter period he also attended the Aberystwyth Technical School, and from 1906-8 he studied at the City and Guilds of London Central Technical College, where he gained First Class Honours, Silver Medal and Goldsmith Prize. His apprenticeship of five years was served in the engineering works of Messrs. T. Williams and Sons, of Aberystwyth, and on its completion in 1905 he obtained one year's workshop practice with Messrs. Vickers, Sons and Maxim, Ltd., Barrow-in-Furness. In 1906 he became assistant engineer and partner in the firm of Messrs. T. Williams and Sons, Aberystwyth. In this connection he designed various hydraulic turbines, turbo-electric stations, mining machinery, etc., and also acted as works manager to the firm. His death took place at Aberystwyth on 7th August 1913, in his twenty-ninth year. He was elected an Associate Member of this Institution in 1910.

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CHAPMAN, J. F., elected Associate Member, 1250.

CHARNOCK, G. F., Remarks on Engineering Research, 909.

CHITTENDEN, E. B., Memoir, 1332.

CLARK, J. J., elected Associate Member, 673.

CLARKE, A. V., Associate Member transferred to Member, 992.

CLEMENTS, F., Associate Member transferred to Member, 1251.

COLE, D. B., elected Associate Member, 990.

CONSTANTINE, W. W., elected Associate Member, 673.

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COUBROUGH, A. C., elected Member, 672.

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COVE, E. E. A., elected Associate Member, 673.

COX, W. T., elected Associate Member, 1250.

CRANE WORKS, Bedford, 970.

CRANFIELD BROTHERS, Flour Mills, Ipswich, 949.

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CROCKER, E. G., Associate Member transferred to Member, 675.—*Paper* on the Drainage of the River Ouse Basin, 805.—Remarks thereon, 846, 859.

CROMPTON, Col. R. E. B., C.B., R.E., *Paper* on Mechanical Engineering Aspects of Road Construction, 1253.—Remarks thereon, 1310, 1326.

CROMPTON, W. E., elected Associate Member, 990.

CROSLAND, J. F. L., Remarks on Gas-Engine Cooling, 704.

CULLY, W. F., elected Associate Member, 990.

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DADSWELL, J., elected Associate Member, 673.

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DAVEY, H., Remarks on Gas-Engine Cooling, 701.

DAVIES, F. D., elected Associate Member, 1250.

DAVIES, V. C., elected Associate Member, 673.

DAVISON, R., Memoir, 1333.

DAWSON, T., elected Associate Member, 990.

DAY, C. H. J., elected Associate Member, 673.

DAY, F. D., elected Associate Member, 990.

DEARDEN, W. H., elected Associate Member, 673.

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DUNBAR, J., elected Associate Member, 1250.

DUNCAN, G. T., elected Member, 672.

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EIGENBERTZ, H., elected Associate Member, 673.

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FEWSTER, E. D., elected Associate Member, 990.

FILDES, P. A., elected Member, 672.

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FORD, H. H., Associate Member transferred to Member, 992.

FOWLER, J. A., elected Member, 672.

FRANCIS, W. H., Mayor of Cambridge, Welcome at Cambridge Summer Meeting, 667.—Remarks at Institution Dinner, Cambridge, 925.

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GARNER, H. C., elected Associate Member, 990.

GARRATT, H. W., Memoir, 1334.

GARTSIDE, V., elected Member, 672.

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GAVIN, N. A., elected Associate Member, 673.

GIBSON, H. F. H., elected Associate Member, 673.

GILLETT, T., elected Associate Member, 1250.

GLASER, W. H., Remarks on Modern Flour-Mill Machinery, 1047.

GLAZE, C. W. L., elected Member, 1249.

GLAZEBROOK, R. T., C.B., Remarks on Temperature Measuring, 762, 771.

GOODCHILD, G. W., Remarks on Cutting Power of Lathe Turning Tools, 1198.

GOODYEAR, W., Associate Member transferred to Member, 1251.

GOUDIE, H. J., elected Associate Member, 990.

GRAFTON AND CO., Vulcan Works, Bedford, 970.

GRAHAM, J., Associate Member transferred to Member, 1251.

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GRANTHAM, R. F., *Paper* on The Drainage of the Fens, 777.—Remarks thereon, 857.

GREEN, T., elected Associate Member, 1250.

GREENLAND, H. F. A., elected Associate Member, 990.

GRIERSON, R., elected Associate Member, 1250.

GRIFFITHS, D. N., elected Associate Member, 1250.

GRIFFITHS, R. S., elected Associate Member, 1250.

GROVE, E. P., elected Member, 990.

GURNHILL, J. B., elected Graduate, 1251.

GUSH, A. S., Eng. Lieut. R.N., elected Associate Member, 990.

HADFIELD, Sir R. A., Remarks on Temperature Measuring, 766.

HALLOWELL, W., elected Associate Member, 1250.

HAMBLIN, W. G., elected Associate Member, 673.

HAMILTON, B. H. N. H., elected Associate Member, 990.

HAMILTON, F. B., elected Associate Member, 1250.

HARGREAVES, W., elected Associate Member, 1250.

HARRIS, L. A. P., elected Graduate, 674.

HARTREE, R., elected Associate Member, 990.

HAWES, J. W. H., elected Associate Member, 1250.

HAWKSLEY, C., appointed Member of Council, 671.—Remarks on Gas-Engine Cooling, 703:—on Fen Drainage, 842:—on first "Thomas Hawksley" Lecture, 1213:—on Road Construction, 1303.

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Heap, A. C., elected Member, 1249.
Heath, G. A., elected Associate Member, 673.
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Henderson, C. G., elected Graduate, 1251.
Herbert, E. G., Remarks on Cutting Power of Lathe Turning Tools, 1148.
Hetherington, E. P., Remarks on Cutting Power of Lathe Turning Tools, 1166.
Hiller, L., elected Associate Member, 673.
Hinde, G., elected Member, 990.
Holmes, H., elected Associate Member, 990.
Homewood, G., elected Associate Member, 1250.
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Hoskyns, O. P. L., elected Associate Member, 673.
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Houston, R., elected Associate Member, 673.
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Howie, H. A., elected Associate Member, 1250.
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Hubble, A. W., elected Associate Member, 673.
Hugill, R. C., Eng.-Lieut., R.N., elected Associate Member, 673.
Humphrey, H. A., Remarks on Fen Drainage, 832, 838.
Hutchinson, E. G., elected Associate Member, 673.

Inglefield, A. F., Lieut. R.N., elected Graduate, 1251.
Ingouville, P., elected Associate Member, 1250.
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JACKSON, G. J., elected Associate Member, 990.
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JEEJEEBHOY, P. B., Memoir, 1335.
JEFFERY, C. F., elected Associate Member, 673.
JELBERT, W., elected Associate Member, 673.
JENKIN, C. J., Remarks on Road Construction, 1305.
JINASENA, C., elected Associate Member, 1250.
JOHNS, C., Remarks on Temperature Measuring, 768.
JOHNSTON, W. A., elected Associate Member, 990.
JOLLY, J. B., elected Associate Member, 673.
JONES, C. H., elected Graduate, 1251.
JONES, J. C., elected Associate Member, 673.
JONES, S. W., elected Associate Member, 990.
JOY, B. H., elected Member, 672.
JOYCE, P., elected Associate Member, 673.
JUDD, W. W., Memoir, 1336.

KELLOW, M., elected Member, 1249.
KENNEDY, S. S., elected Associate Member, 673.
KENT, W. M., Memoir, 1337.
KILLICK, J. S., Remarks on Road Construction, 1322.
KNOCKER, G. S., Associate Member transferred to Member, 675.

LARMOR, Sir J., M.P., Remarks at Institution Dinner, Cambridge, 926.
LATHAM, E., elected Associate Member, 673.
LATHE TURNING TOOLS, Cutting Power, 1067. *See* Cutting Power of Lathe Turning Tools.
LAYCOCK, W. E., elected Associate Member, 673.
LECTURE, "THOMAS HAWKSLEY," 1913, 1215.
LEEDS, Delivery of "Thomas Hawksley" Lecture at, 1214.
LINDSAY, W. J., elected Associate Member, 990.
LINNELL, A. E., Associate Member transferred to Member, 992.
LITTLE, Eng. Rear-Admiral E., Remarks on Gas-Engine Cooling, 698:—on Temperature Measuring, 766:—on Engineering Research, 905.
LIVERPOOL, Delivery of "Thomas Hawksley" Lecture at, 1214.
LLOYD, G. W., elected Associate Member, 991.
LOCKER, T. C., elected Graduate, 674.
LOEWE, D. L., elected Associate Member, 674.
LONDON, A. G., elected Associate Member, 991.

LONGRIDGE, M., Remarks on Gas-Engine Cooling, 700:—on Fen Drainage, 839:—on Engineering Research, 911.
LOW, W. L. S., Memoir, 980.
LUDLOW, W. A. C., elected Graduate, 1251.
LYNTON WORKS, Bedford, 972.

MACAULAY, M. S., elected Associate Member, 1250.
MCCORMICK, J., elected Associate Member, 991.
MCCOURT, E. F., elected Associate Member, 991.
MCGILL, J., elected Member, 672.
MACKAY, J. C., Remarks on Road Construction, 1297.
MCKENZIE, N., elected Associate Member, 674.
MACKENZIE, R. A., elected Associate Member, 991.
MACLEAN, A. F., elected Associate Member, 991.
MCVICAR, A., elected Member, 1249.
MACHINERY for Modern Flour-Mills, 993. *See* Flour-Mill Machinery.
MAIN, G. W., elected Associate Member, 991.
MAIR, G. P., Remarks on Fen Drainage, 848.
MALLINSON, A. B., Associate Member transferred to Member, 1251.
MANCHESTER MEETING, 1913, Remarks by the President, 988.—Business, 1065.
MANICO, E. L., elected Associate Member, 1250.
MARRIOTT, T. G., Remarks on Road Construction, 1298.
MARTEN, H. B., Associate Member transferred to Member, 675.
MASLIN, E. S., elected Associate Member, 674.
MASSEY, L. F., Remarks on Road Construction, 1304.
MATTHEWS, T. L., Associate Member transferred to Member, 992.
MAUNSELL, R. G. F., elected Graduate, 674.
MAYNARD, P. V., elected Associate Member, 991.
MEASURING TEMPERATURE, Methods, 717. *See* Temperature Measuring.
MEETINGS, 1913, Cambridge, 663.—October, 987.—November, 1065, 1066.—December, 1211, 1249.
MEMOIRS of Members recently deceased, 977, 1329.
MILLINGTON, E., Remarks on Cutting Power of Lathe Turning Tools, 1172.
MILNE, E. N., elected Associate Member, 674.
MITCHELL, G., Remarks on Modern Flour-Mill Machinery, 1049.
MITCHELL, J., elected Associate Member, 991.
MOFFATT, D., Associate Member transferred to Member, 992.
MOLYNEUX, T., elected Member, 672.
MOORE, W. L., Eng.-Com., R.N., Memoir, 981.
MOSS, H., elected Associate Member, 1250.

NAKAI, U. S., elected Graduate, 1251.
NASMITH, J., Associate Member transferred to Member, 1251.

Naylor, T. L., elected Associate Member, 991.
Nelson, G. H., Remarks on Cutting Power of Lathe Turning Tools, 1170.
Nelson, L., elected Associate Member, 991.
Newton, E. V., Associate Member transferred to Member, 1251.
Norris, J. W., elected Graduate, 674.
Norrish, H. R. B., elected Associate Member, 674.
Norton, S. J., elected Associate Member, 991.
Nottingham, Delivery of "Thomas Hawksley" Lecture at, 1214.
November Meetings, 1913, 1065, 1066.

Observatory, Cambridge, Visited at Cambridge Summer Meeting, 923.—Description, 942.
October Meeting, 1913, Business, 987.
Ord, J. T., elected Associate Member, 1250.
Orwell Works, Ipswich, 956.

Page, J. H., Associate Member transferred to Member, 675.
Panton, W. D., elected Associate Member, 674.
Park, P. McA., elected Associate Member, 674.
Parsons, C. G., elected Graduate, 1251.
Parsons, H. A., elected Associate Member, 1250.
Partridge, C. F., elected Graduate, 1251.
Patchell, W. H., Remarks on Gas-Engine Cooling, 702:—on Temperature Measuring, 768:—on Fen Drainage, 849.
Pell, H. W. L., elected Associate Member, 1250.
Pendred, L., Remarks on Cutting Power of Lathe Turning Tools, 1180.
Percy, H. L., Associate Member transferred to Member, 1066.
Pertwee, H. A., Associate Member transferred to Member, 992.
Phillips, G. W., elected Associate Member, 991.
Pitt, R. W., elected Associate Member, 674.
Pitt, W., Remarks on Gas-Engine Cooling, 703.
Plansifters, 1014. *See* Flour-Mill Machinery.
Portland Cement Works, Visited at Cambridge Summer Meeting, 923.—Description, 933, 973.
Portrait of Thomas Hawksley. *See* Frontispiece to Part 4, 1913.
Powell, F. E., Remarks on Road Construction, 1328.
Powell, H., elected Associate Member, 991.
Power of Lathe Turning Tools, Cutting, 1067. *See* Cutting Power of Lathe Turning Tools.
Preece, Sir W. H., K.C.B., Memoir, 1337.
Pretty and Sons, Corset Factory, Ipswich, 931, 950.
Printing Works, Cambridge, 941.

Prothero, E. G., elected Graduate, 1251.

Pumping Machinery (Modern) for Fen Drainage, 787, 805. *See* Papers on Drainage of the Fens.

Punter, A., elected Associate Member, 991.

Purse, F. W., Associate Member transferred to Member, 675.

Pye, T. E., Memoir, 1339.

Pyrometers, Optical and Radiation, 744. *See* Temperature Measuring.

Queen's Engineering Works, Bedford, 964.

Quennell, W. A., Capt. A.O.D., elected Member, 1249.

Ranelagh Works, Ipswich, 962.

Ransome, A., Memoir, 981.

Ransomes and Rapier, Waterside Iron Works, Ipswich, Visited at Cambridge Summer Meeting, 931.—Description, 951.

Ransomes, Sims and Jefferies, Orwell Works, Ipswich, Visited at Cambridge Summer Meeting, 931.—Description, 956.

Rappoport, F. G., Associate Member transferred to Member, 675.

Rathmell, B., elected Member, 672.

Reavell and Co.'s Works, Ipswich, Visited at Cambridge Summer Meeting, 930.—Description, 962.

Reavell, W., Remarks on Gas-Engine Cooling, 699.

Reception at Trinity Lodge, Cambridge, 930:—in the Guildhall, Cambridge, 930:—at the Institution, London, 1213.

Reed, F. W., elected Member, 672.

Reed, H. A., elected Member, 1249.

Rees, J. H., elected Associate Member, 674.

Reid, F. H., elected Graduate, 991.

Research, Engineering, 869. *See* Engineering Research.

Ridgway, A. E. A., elected Associate Member, 1250.

Riehn, J. F., elected Associate Member, 1250.

Riley, H. P., Memoir, 1339.

Ripper, W., Remarks on Gas-Engine Cooling, 696.—*Paper* on Cutting Power of Lathe Turning Tools, 1067.—Remarks thereon, 1174, 1185, 1193, 1199.

Road Construction, *Paper* on Mechanical Engineering Aspects of Road Construction, by Col. R. E. B. Crompton, C.B., R.E., 1253.—Vehicle and road interdependent, 1253; success of steam-train in India; prophecy by H. G. Wells, 1254; traction-engine design practically unchanged since 1861; effect of rubber tyres on weight, 1255; removal of speed restrictions, 1256; reduction of repairs, by changes in gearing and springs, 1257; development of motor-omnibus traffic, 1258.—Deformation of road surface, 1259.—Formation of Road Board, 1259.—

Trials of road surfacing material, 1260; irregular wear of roads due to deformation; causes of deformation, 1262; wave formation, 1263; due to harmonic motion of motor-vehicles; shifting of material on roads, 1264; horse-drawn traffic more heterogeneous and non-harmonic than motor traffic, 1266.—Machine for comparing efficiency of methods of road construction, 1267.—Initial waves on newly-formed road surfaces, 1269.—Three-axle roller, 1271.—Large wheel-diameters, 1273.—Improvement of road surfaces, 1275.—Reconstruction with road material coated with bituminous binders, 1276.—Grouting or penetration methods, 1277.—Sheet asphalt or double-coat work, 1277.—Material available for double-coat work, 1278.—Machinery for preparing sheet asphalt, 1279.—Road material should be accurately tested, 1284.—Advantages of rolling down hot material, 1286.—Cylindrical driers, 1288.—Batch mixers, 1290.—Conical rotating mixer, 1292.—Rotating hand-mixer, 1292.—Combined heating and mixing machinery, 1293.—Economical considerations, 1293.—Assumed future reduction of running costs, 1294.

Discussion.—Donaldson, Sir H. F., Thanks to author, 1296.—Thornycroft, Sir J. I., Road should be watertight, 1296.—Mackay, J. C., Stones should be flat instead of cubical shape, 1297; good foundation essential, 1298.—Marriott, T. G., Standardization of haulage systems, 1298; sheet asphalt more satisfactory than block paving, 1299.—Dryland, A., Materials laid hot more liable to form waves, 1300; effect of weight of vehicles on road; importance of effect of wheel diameter; admirable results obtained from use of tarred slag, 1301; assumed future reduction of cost, 1302.—Hawksley, C., Laying of pipes breaks foundation of road, 1303.—Robinson, M., Wave formation and movement of ridges, 1303; cross-ridges, 1304.—Massey, L. F., Movement of waves and valleys, 1304; applications of resilient concrete, 1305.—Jenkin, C. J., Waves and valleys move in direction of traffic, 1305; rhythmic motion of wheels dependent on length of wheel-base; shape of stone used; experimental machine, 1306.—Beaumont, W. W., "Lightning" crusher, 1307; harmonic impact and three-axle roller, 1308; effect of rolling hard and soft material, 1309.—Crompton, Col. R. E. B., Wave formation, 1310; effect of hot-rolling, 1311; wave-formation also caused by horse-traffic, 1312; breaking of wave crests; slag more plastic than granite; radial traverse of experimental machine; laying of pipes, 1313; durability of road surfaces; bituminous concrete for foundations; uncertainty of climate affects cost of construction, 1315.

Communications.—Fearnsides, W. G., Geological aspect of wave-formation, 1316; moving of material by percussive action, 1318;

double-coat work, 1319.—Hooley, E. P., Surveyors' view of road deformation, 1320; causes of waves; experiments prevented by absence of funds, 1321.—Killick, J. S., Running costs reduced by road reconstruction, 1322; revised cost, 1323.—Wood, F., Rhythmic action of wheels generated by springs, 1323; effect of motor-omnibuses, 1324; effect of rolling and over-rolling, 1325.—Crompton, Col. R. E. B., Difficulties of road surveyors; introduction of tar-slag macadam, 1326; cost of asphaltic surfaces, 1327; waves originate by projections in roads, 1328.—Powell, F. E., Effect of climate on roads, 1328.

ROBERTS, E. F., elected Associate Member, 991.

ROBERTS, G. H., *Paper* on Engineering Research and its Co-ordination, 869.—Remarks thereon, 907, 914:—on Cutting Power of Lathe Turning Tools, 1182.

ROBERTSON AND Co., Lynton Works, Bedford, 972.

ROBINS, F. S., Remarks on Fen Drainage, 851.

ROBINSON, C. J., Remarks on Modern Flour-Mill Machinery, 1033.

ROBINSON, J. E., elected Member, 990.

ROBINSON, M., appointed Vice-President, 671.—Remarks on Road Construction, 1303.

RODDA, H. C., elected Associate Member, 1250.

ROGERS, L. N., elected Graduate, 1251.

SANDBERG, C. P., Memoir, 1340.

SANDERS, F. A. H., elected Associate Member, 674.

SANTOS, A. V. DOS, elected Graduate, 991.

SAXON, A., Remarks on Cutting Power of Lathe Turning Tools, 1143.

SAXON AND NORMAN CEMENT WORKS, Cambridge, 933.

SCOOP WHEELS. *See* Fen Drainage.

SHARP, J. H., Memoir, 1341.

SIEMENS, A., Remarks on Gas-Engine Cooling, 701:—on Engineering Research, 904.

SILOS for Grain, 1021. *See* Flour-Mill Machinery.

SIMON, E. D., Remarks on Modern Flour-Mill Machinery, 1052.

SIMPSON, F. D., elected Associate Member, 1250.

SKINNER, A. J., elected Graduate, 1251.

SMITH, C. H., elected Graduate, 1251.

SMITH, D., Remarks on Cutting Power of Lathe Turning Tools, 1159.

SMITH, F. B., elected Associate Member, 991.

SMITH, M. H., Remarks on Gas-Engine Cooling, 703:—on Fen Drainage, 852.

SMITH, R. H., Remarks on Cutting Power of Lathe Turning Tools, 1187.

SMITH, W. A. P., Eng. Comm., R.N., elected Member, 672.

SNELGROVE, E. C., elected Graduate, 675.

Somers, F., Associate Member transferred to Member, 992.

Soward, H. W. F., elected Associate Member, 674.

Speight, J. E., Remarks on Modern Flour-Mill Machinery, 1038.

Spooner, H. J., Remarks on Gas-Engine Cooling, 711:—on Engineering Research, 912.

Stackard, S. F. C., elected Graduate, 1251.

Standley, G. A., elected Associate Member, 674.

Start, S. P., Eng. Lieut., R.N., elected Member, 672.

Stewart, C. E., elected Associate Member, 1250.

Stokes, H. P., elected Associate Member, 674.

Strong, G. H., elected Member, 672.

Summer Meeting, 1913, Cambridge, 663.

Sundon Cement Works, 973.

Sutcliffe, W., elected Member, 672.

Tannett-Walker, A. T., Resignation of Vice-Presidency, 671.

Taylor, W. H., elected Associate Member, 674.

Temperature Measuring, *Paper* on Modern Methods of Measuring Temperature, by R. S. Whipple, 717.—Expansion thermometers, 717; scales of measurement; standard glasses for tubes, 718; correction of errors, 719; types of mercury thermometers, 720; tube-protecting devices, 721; recording mercury thermometers at a distance, 722; metal tubes instead of glass, 723; thermograph and index thermometer, 724.—Thermo-electric thermometers, 725; thermo-couples, 726; electromotive forces given by thermo-couples, 727; control of temperature of cold-junction control, 728; thermos-flask cold junction control, 729; steam hypsometer control; measurement of thermo-electric force, 730; potentiometric method, 732.—Autographic recorders; thread recorder, 734; scale-control board, 736.—Resistance thermometers, 738; Wheatstone bridge arrangement, 741; Callendar recorder, 743.—Optical and Radiation pyrometers, 744; "black-body" conditions, 745; Féry's radiation pyrometer, 750; fixed focus pyrometer, 751; limitations of pyrometers, 752.—Practical considerations, 753; steam plant; cold storage; treatment of metals; blast-furnace work, 754; casting temperatures; annealing and hardening, 755; brick and porcelain works, 757.—Experimental work, 758.—Standardization of thermometers, 759.

Discussion.—Donaldson, Sir H. F., Careful handling of thermometers, 761.—Darwin, H., Index thermometer, 761; Callendar recorder, 762.—Glazebrook, R. T., Verification and Standardization at the National Physical Laboratory, 762; measurement of high temperatures, 764.—Wicksteed, C., Effect of small differences of temperature, 764; utility of recording clock, 765.—Little, Eng. Rear-Adm. E., Fusing points of metals, 766.—Hadfield, Sir R. A., Difficulty of obtaining uniform temperatures, 766; determining temperature of molten metals, 767.—Patchell, W. H., Thermometers for taking steam temperatures, 768.—Johns, C., Negligible errors of instruments, 768; sources of errors; nitrogen thermometer, 769; calibration of instruments, 770.—Glazebrook, R. T., Calibration, 771.—Whipple, R. S., Standardization of pyrometers, 771; temperatures of molten metals; automatic recorder, 772.

Communications.—Brayshaw, S. N., Satisfactory working of thermocouple indicators, 773; Whipple indicator; Callendar recorder; Féry pyrometer, 774; alloy for standardization, 775.—Whipple, R. S., Féry pyrometer, 775.

THERMOMETERS, Expansion, 717:—Mercury, 719:—Thermo-electric, 725:—Resistance, 738.—Standardization, 759.

THIEME, H. C. A., elected Associate Member, 674.

THOM, W., Memoir, 983.

"THOMAS HAWKSLEY" LECTURE, 1913, Remarks by the President, 987, 1211, 1212.—*Lecture* by E. B. Ellington, 1215.

THOMAS, H. K., Associate Member transferred to Member, 675.

THOMPSON, H. S. V., elected Associate Member, 1250.

THOMPSON, J., elected Associate Member, 1250.

THORNYCROFT, Sir J. I., Remarks on Road Construction, 1296.

TIMBER, Tests of, 873. *See* Engineering Research.

TITLEY, A., Remarks on Fen Drainage, 854.

TOD, P., elected Member, 672.

TOMLINSON, J. A., elected Associate Member, 991.

TOOLS, Lathe Turning, 1067. *See* Cutting Power of Lathe Turning Tools.

TRANSFERENCES of Associate Members, etc., 675, 991, 1066, 1251.

TREVITHICK, F. H., elected Member, 672.

TRIGLE, S. E., elected Graduate, 1251.

TWELVETREES, R. W. R., elected Associate Member, 991.

TYLER, O. W., elected Graduate, 675.

UNIVERSITY PRESS, Cambridge, 941.

VERNON, H., elected Associate Member, 674.

VOTES OF THANKS at Cambridge Summer Meeting, 676.

VULCAN WORKS, Bedford, 970.

VYLE, G. C., Remarks on Modern Flour-Mill Machinery, 1056.

WALCROFT, T. C., elected Associate Member, 991.

WALE, N. W., elected Associate Member, 674.

Water as a Mechanical Agent, First "Thomas Hawksley" Lecture, by E. B. Ellington, 1215.—Scope of Lectures, 1215.—Water Engineering 100 years ago, 1216.—London water supply in 1827, 1216; quality deficient, 1218.—Engineering education of Thomas Hawksley; construction of Trent Waterworks; constant supply, 1219.—Liverpool Waterworks 1220.—Hawksley's uniform success, and its causes, 1220.—Hawksley, a leading gas and Sanitary Engineer, 1221.—Defects in present system of training Engineers, 1222.—Water as a mechanical agent, 1223.—Flow of water in pipes, 1223.—Gravitation or pumping, 1224.—Recent developments, 1226.—Cornish engine of 1827 compared with recent triple-expansion engine, 1226.—Causes of development in Industries, 1226.—Gravitation and pumping, 1228.—Drainage complementary to water supply, 1230.—Pressure machines and velocity machines, 1230; pipe lines, 1233.—Works at Loch Leven; at Schaffhausen; at Chester, 1234.—Pelton wheels, 1237.—Bramah's expectations, 1237.—Forging presses, 1238.—Cotton and bale pressing, 1239.—Energy available in ordinary water mains, 1239.—Lord Armstrong's inventions, 1240; early works at Newcastle and Grimsby; the accumulator, 1241.—Recent developments in London, Manchester, etc., 1242.—New factor of electricity, 1242.—Relative advantages of Water and Electricity, 1243.—Power in rainfall, 1244.—Thanks for assistance in preparation of Lecture, 1245.—Appendix: Thomas Hawksley's assistance to Birmingham, Leeds, Liverpool, and Nottingham, 1246.

Waterside Iron Works, Ipswich, 951.

Wedge, F. H., Memoir, 983.

Wedlake, J. G., elected Associate Member, 674.

Weekes, B. N., elected Associate Member, 1250.

Western, M. R., Memoir, 1341.

Westley, A. W., Associate Member transferred to Member, 992.

Wheat Distributors, 1022. *See* Flour-Mill Machinery.

Whipple, R. S., *Paper* on Modern Methods of Measuring Temperature, 717.—Remarks thereon, 771, 775.

White, E., elected Member, 672.

Whittaker, M., elected Associate Member, 674.

Wicksteed, C., Remarks on Temperature Measuring, 764.

Wicksteed, J. H., Remarks on Engineering Research, 897.

Wight, J. T., elected Associate Member, 674.

Wilkie, G. M., elected Associate Member, 1250.

Willcox, R. J. N., Remarks on Gas-Engine Cooling, 713.

Williams, A. D., Memoir, 1342.

Williams, G. B., Associate Member transferred to Member, 675.

WILLIAMS, J. Ll., elected Associate Member, 674.
WILLIAMS, R. A., elected Associate Member, 674.
WILLIS, J. H., elected Associate Member, 674.
WILSON, A. B., Memoir, 984.
WINGFIELD, C. H., Remarks on Fen Drainage, 855:—on Engineering Research, 914.
WIRE-DRAWING MACHINERY WORKS, Bedford, 973.
WIRRICK, J. P., elected Associate Member, 674.
WOOD, F., Remarks on Road Construction, 1323.
WOOD, G. T., elected Member, 672.
WOOD, R. D., elected Member, 672.
WOODHAMS, P. P., elected Associate Member, 991.
WOODS, E. W., elected Associate Member, 674.
WOODS, H. F. G., elected Associate Member, 674.
WRIGHT, J. L., elected Associate Member, 991.

YOUNG, S. G., elected Associate Member, 674.

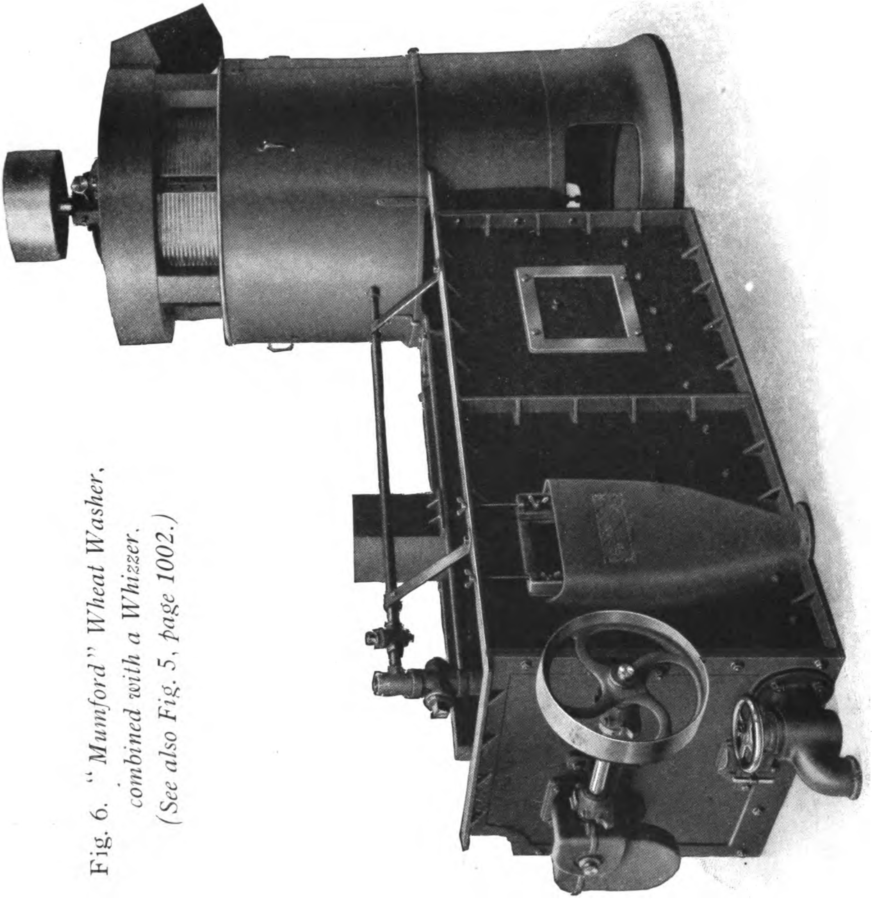
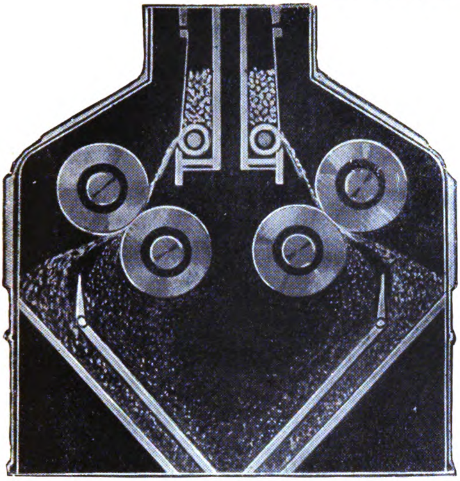


Fig. 6. "Mumford" Wheat Washer, combined with a Whizzer.
(See also Fig. 5, page 1002.)



Pneumatic-Scalping System.
Fig. 11. *Separations obtained in Roller Mill Hopper under System illustrated in Fig. 10. (page 1008.)*

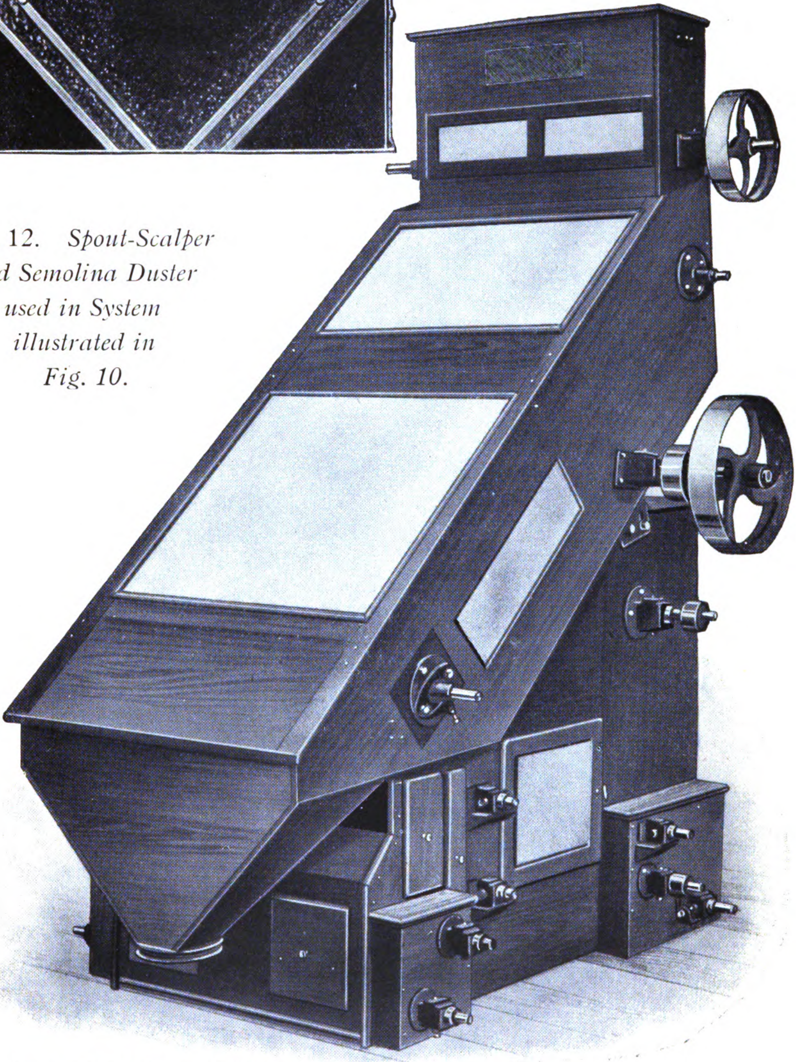


Fig. 12. *Spout-Scalper and Semolina Duster used in System illustrated in Fig. 10.*

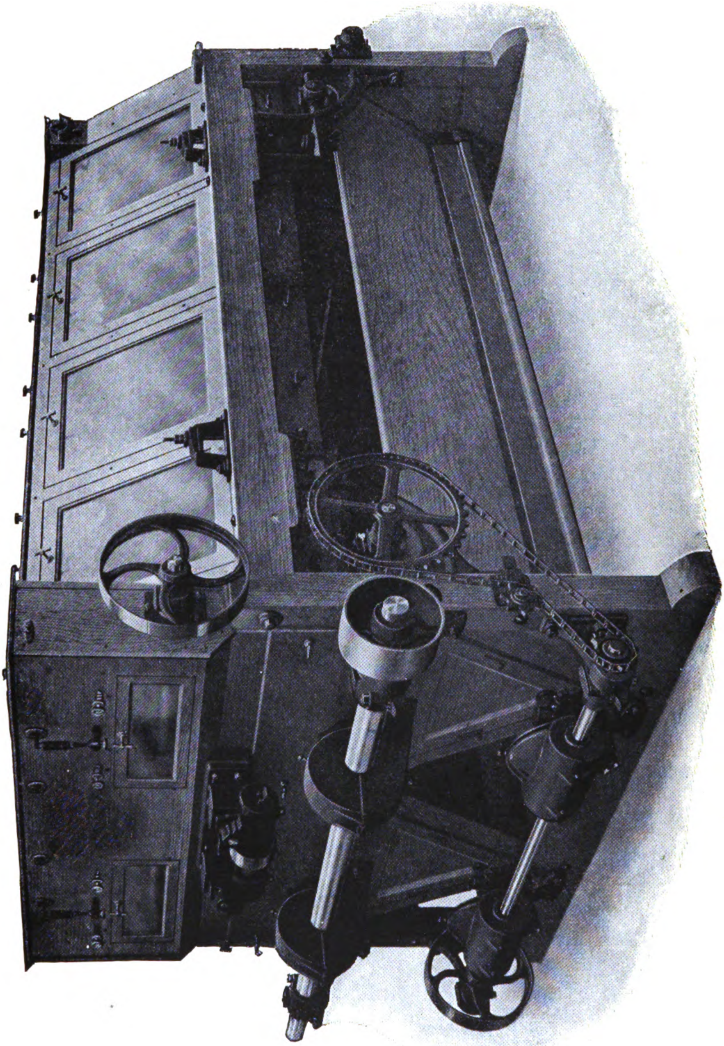


Fig. 14. *Purifier without Fan.*

Fig. 17. *Air-belt Purifier.*

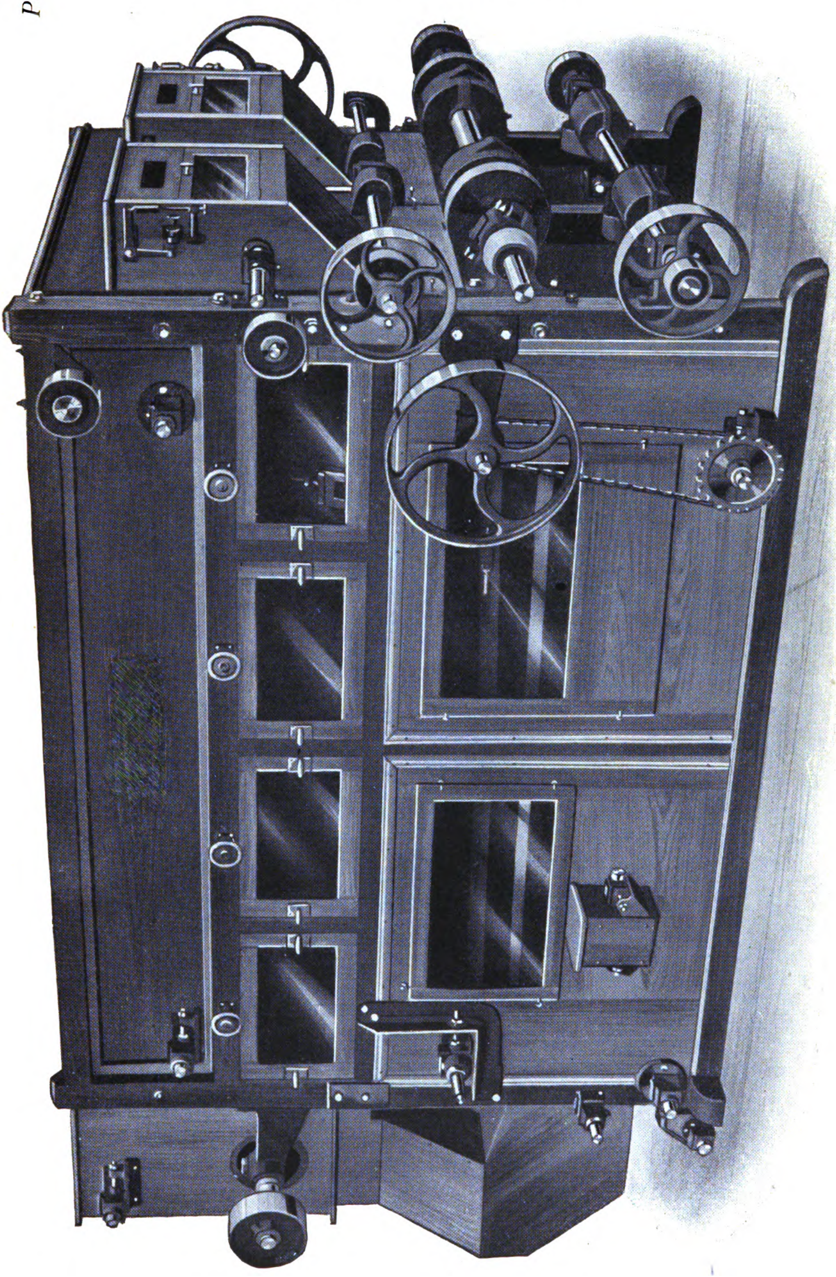


Fig. 18. *Double-Crank Plansifter.*
(See also Figs. 19 to 21, pages 1014-15.)

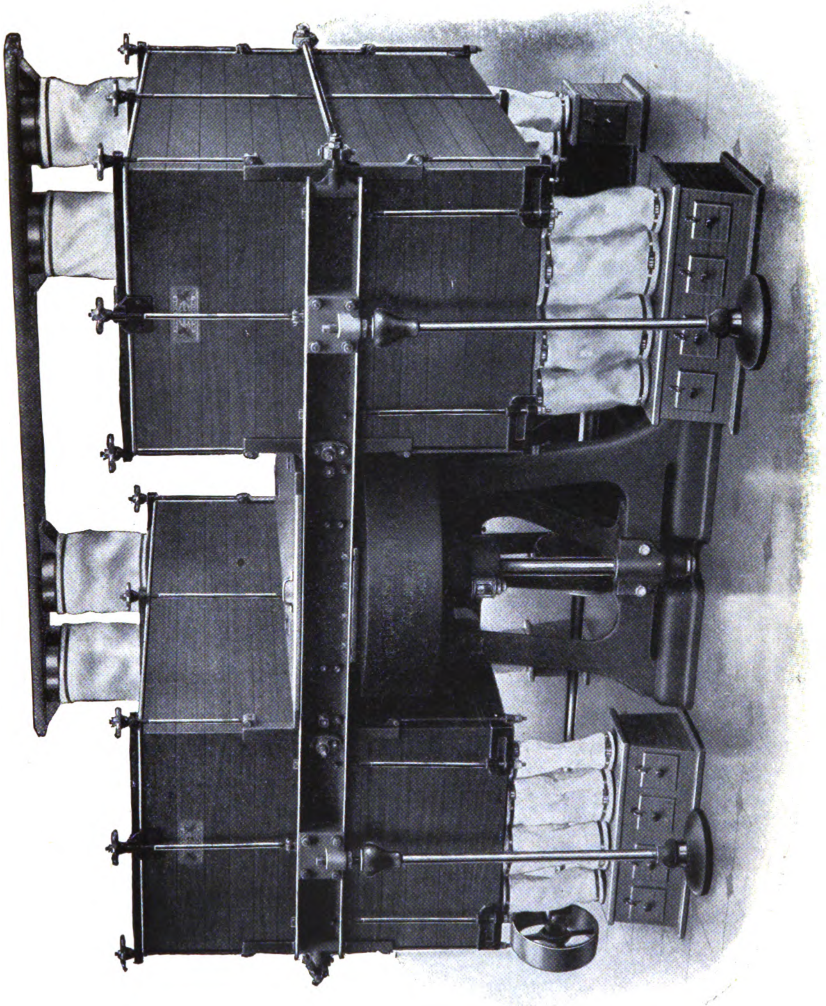
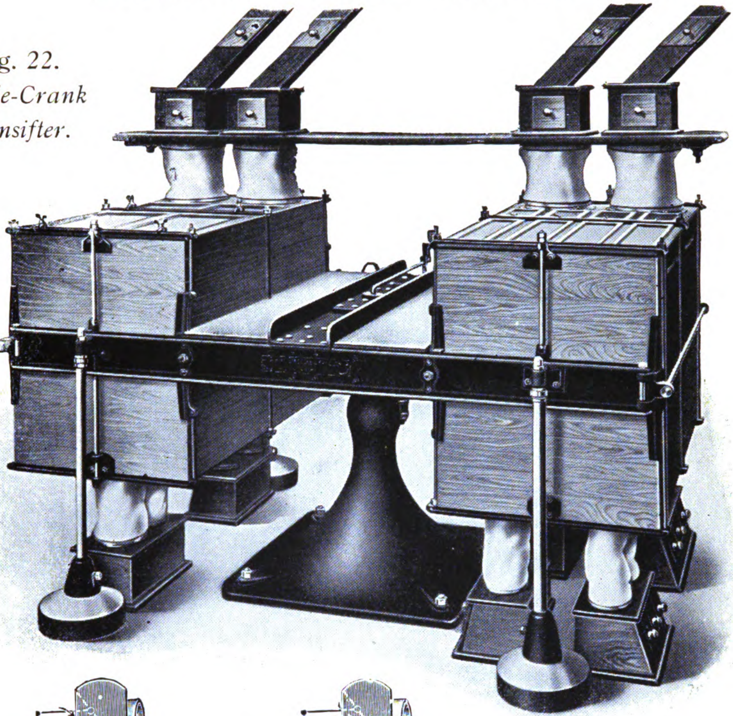


Fig. 22.
Single-Crank Plansifter.



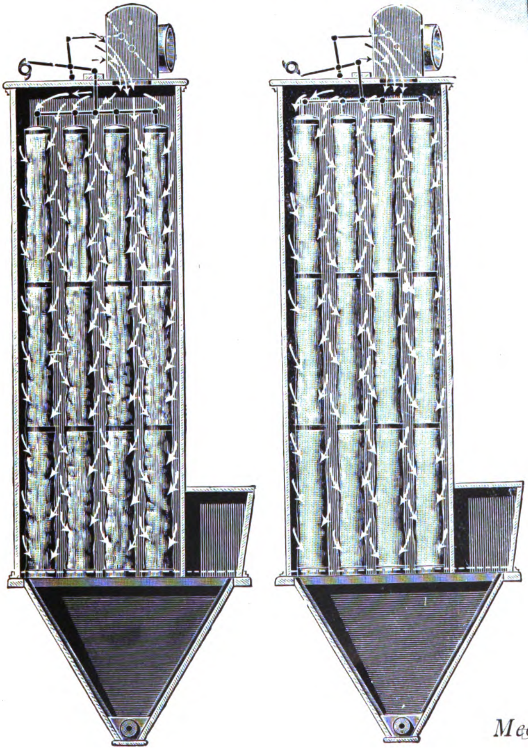


Fig. 23.
Suction Filter Dust-Collector.
(See Plate 31.)

Fig. 24. *Suction Filter Dust-Collector.*

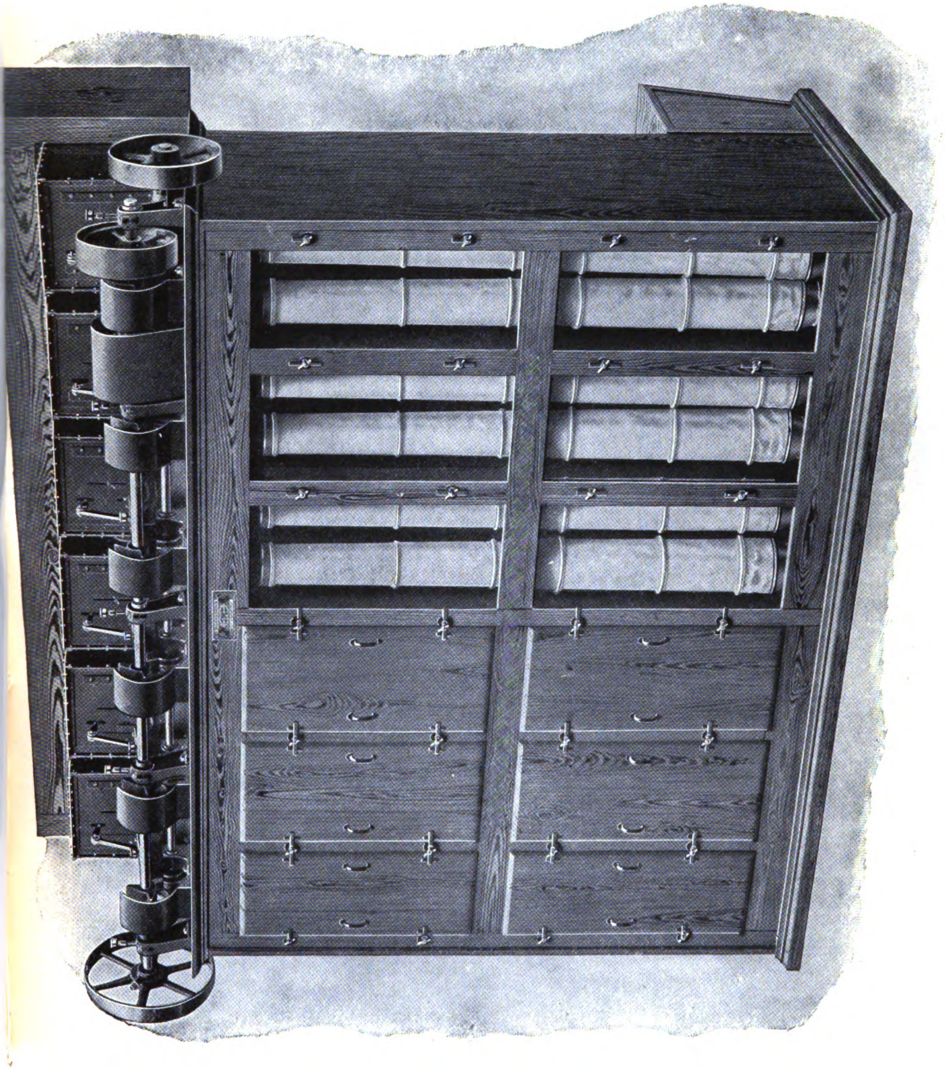


Fig. 25. *Ship Elevator with Fixed Tower.*
Leg raised out of action.

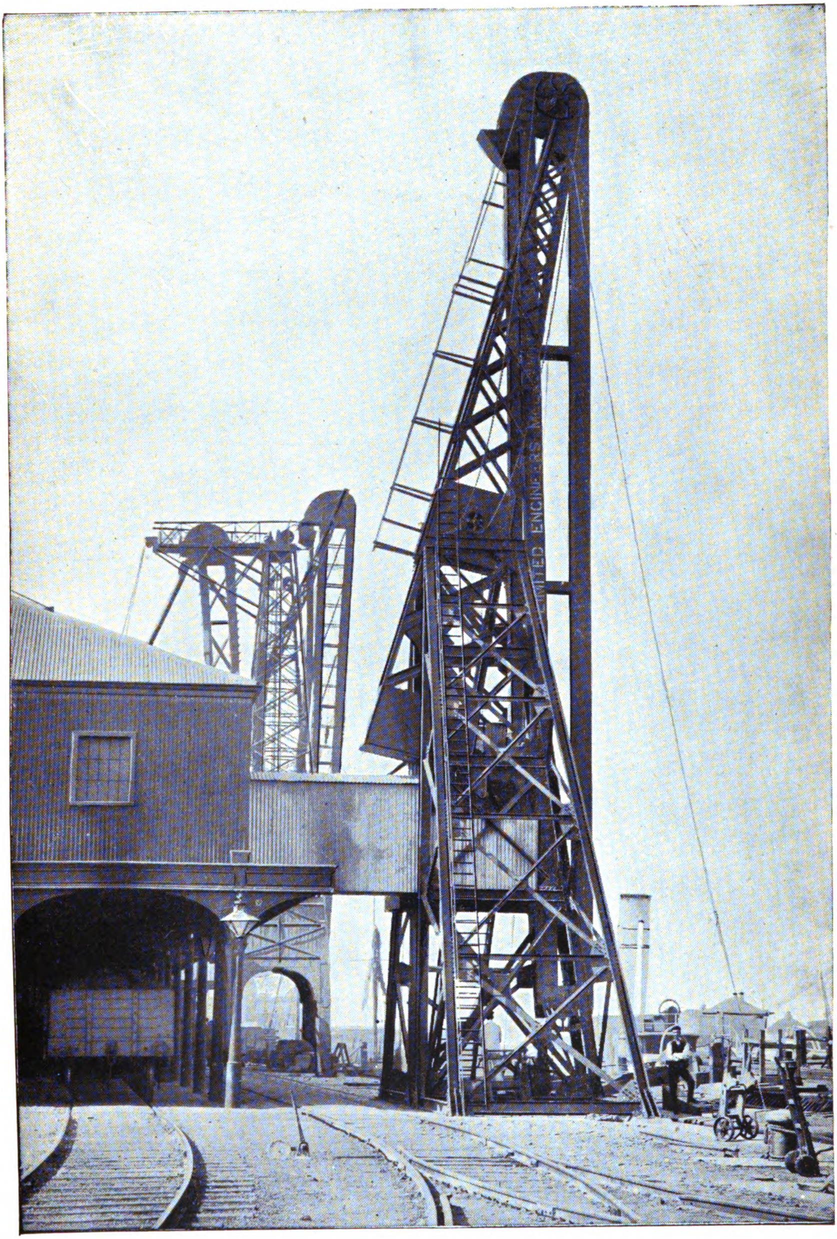


Fig. 26. *Ship Elevator with Travelling Tower.*
Leg lowered in action.

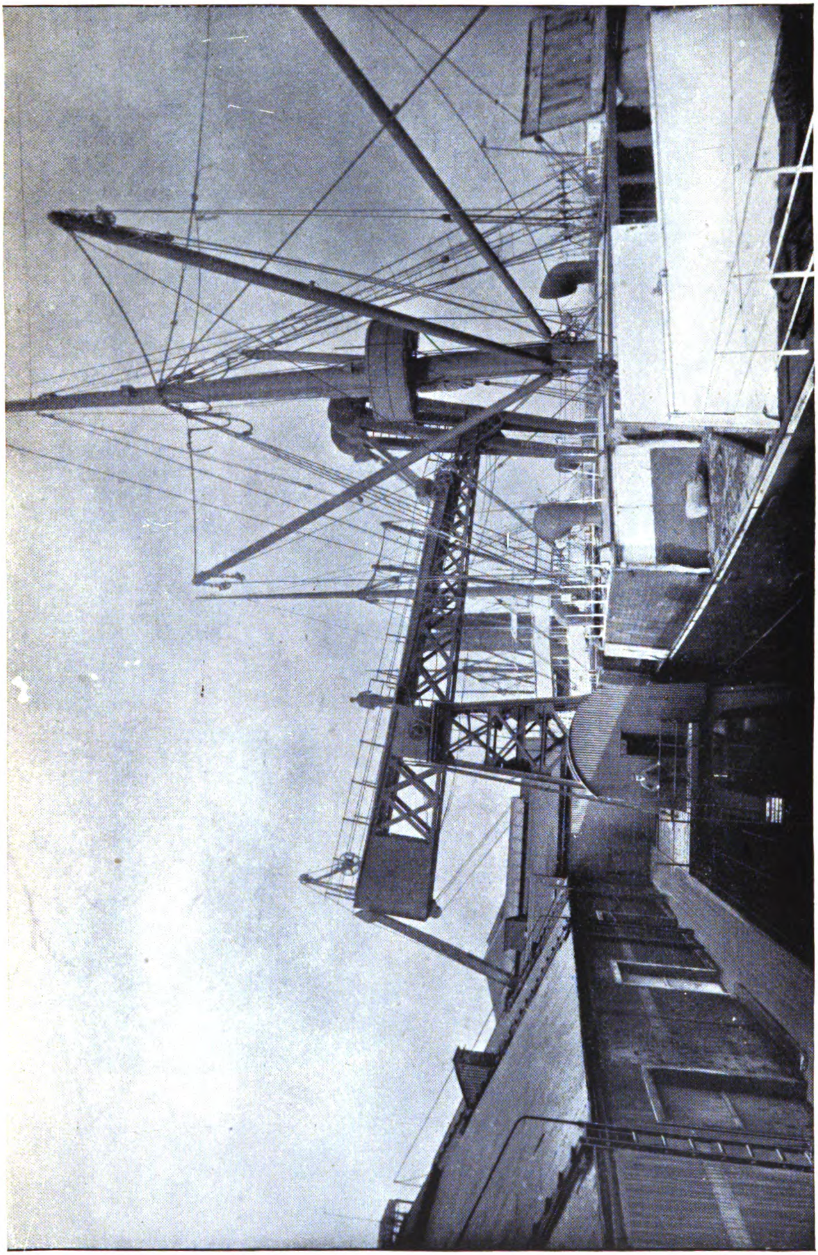
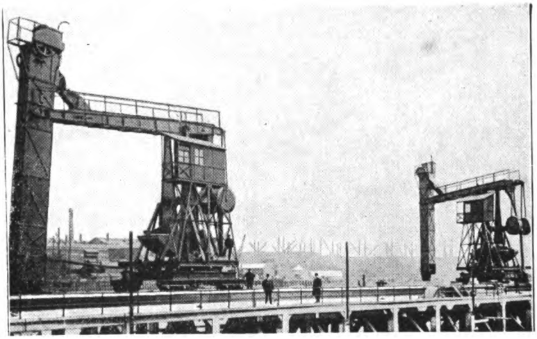
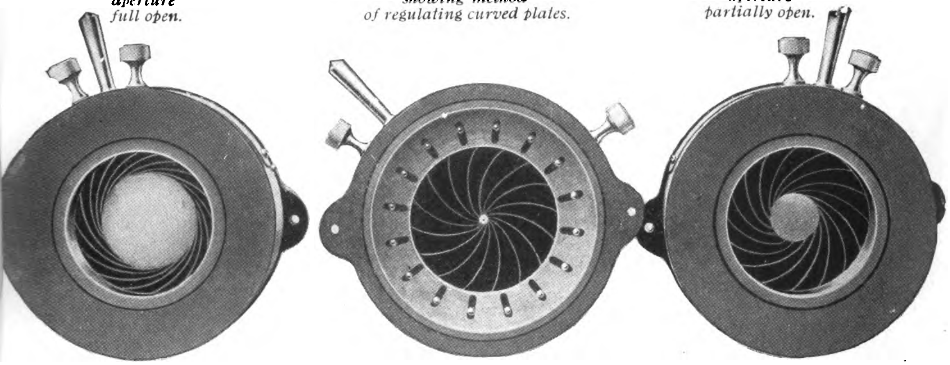


Fig. 27. *Ship Elevator with Travelling Tower.*
Capacity 100 tons per hour. Newcastle-on-Tyne.



Figs. 28 and 29. *Wheat Measurer and Feeder.*

Fig. 28. *Plans.*

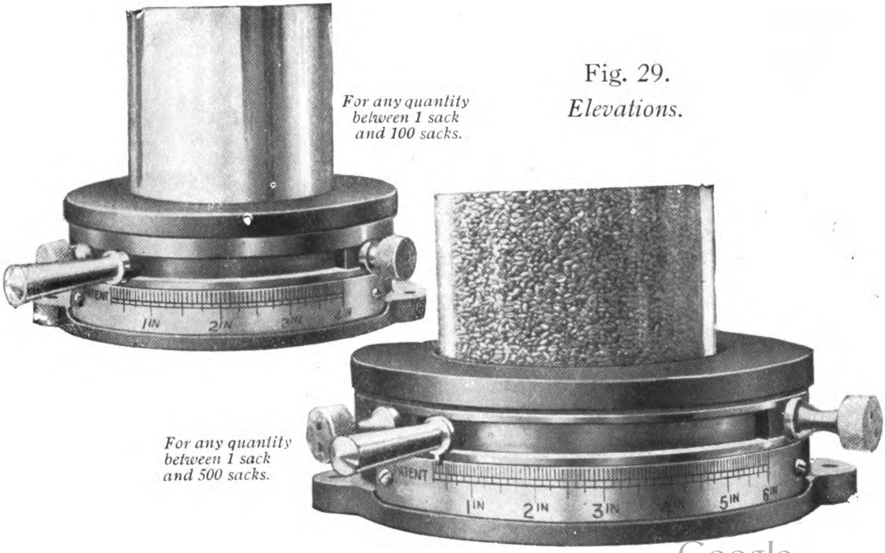


***Top side, aperture** full open.*

***Under side, showing method** of regulating curved plates.*

***Top side, aperture** partially open.*

Fig. 29.
Elevations.



For any quantity between 1 sack and 100 sacks.

For any quantity between 1 sack and 500 sacks.

Fig. 37. *Pneumatic Floating Grain Elevator.*

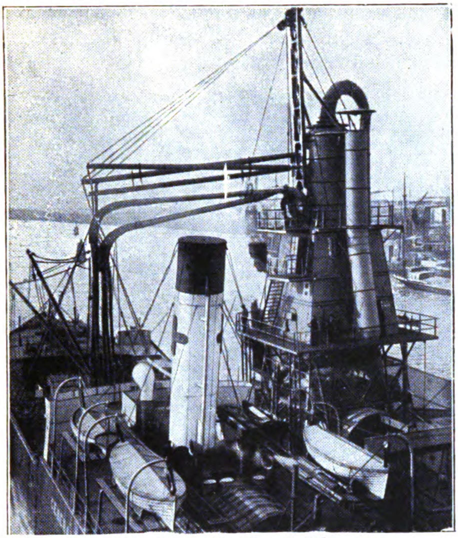


Fig. 42. *Employés Elevator.*

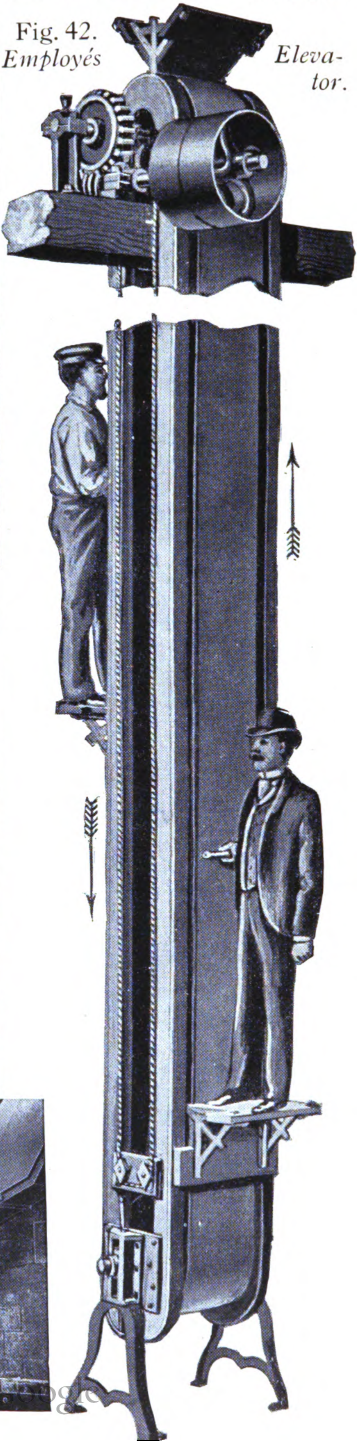
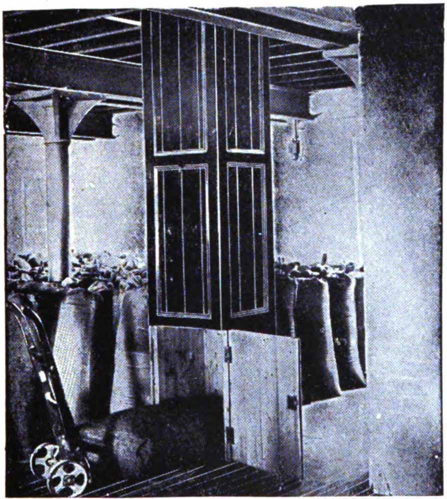
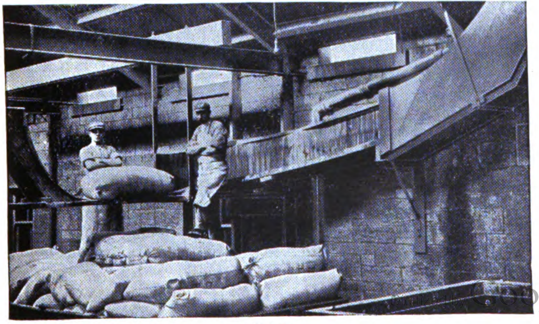


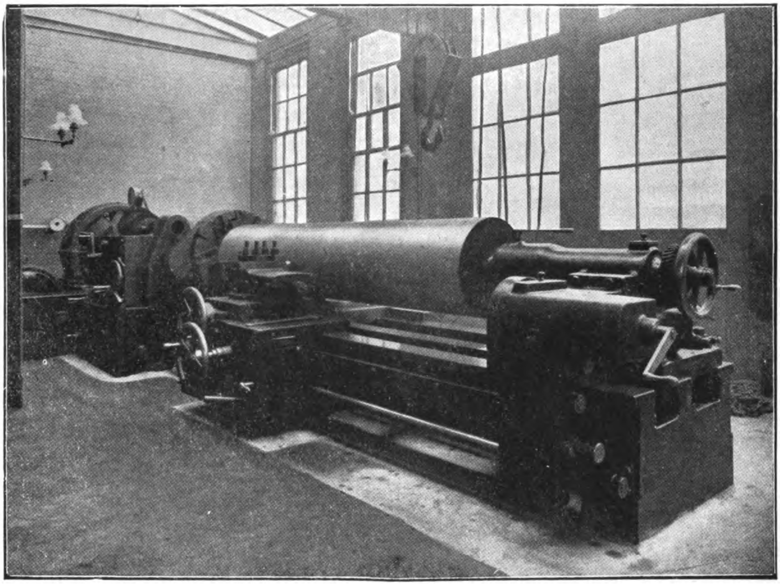
Fig. 39. *Sack Shoot.*





Tool-Steel Testing Lathe in the Engineering Department of the University of Sheffield.

(See Appendix I, page 1124.)



Electrical Plant for Operating Experimental Lathe.

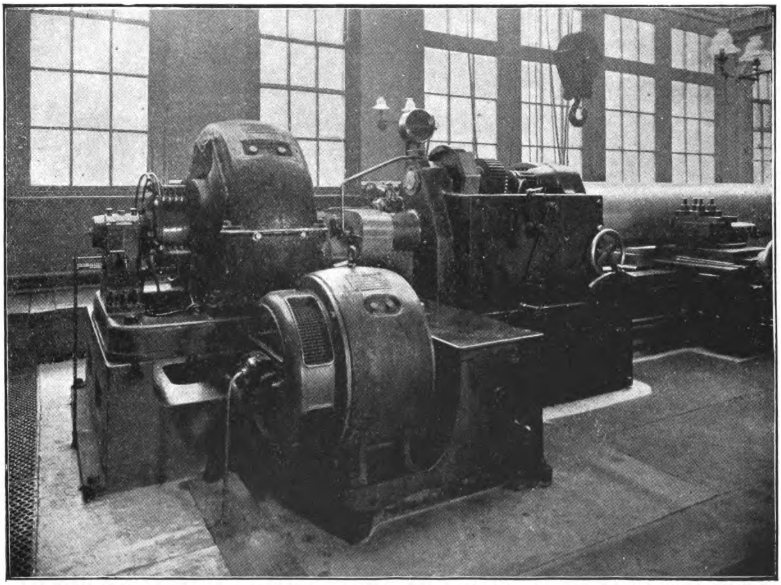


Fig. 3.
Trent Pumping Station.

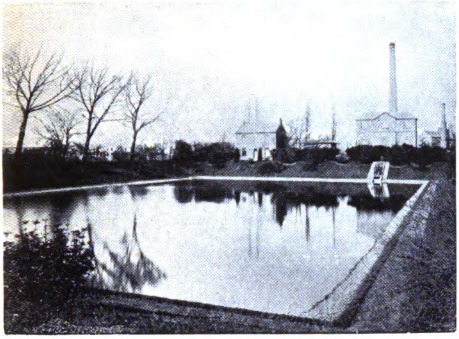


Fig. 4. *Leicester Waterworks.*
Bradgate
Pumping
Station.

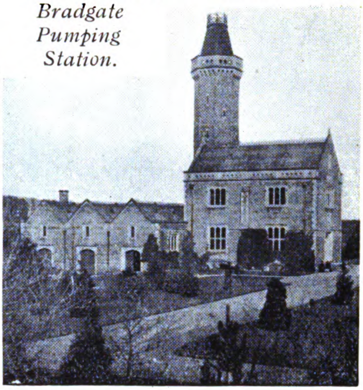


Fig. 5. *Hoisting a Beam.*
Old Style.

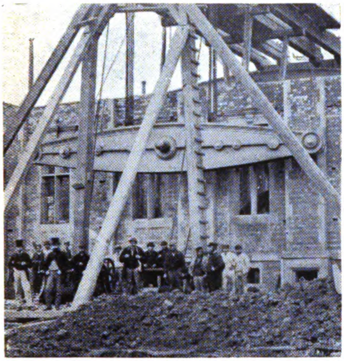


Fig. 6. *Sunderland Gas Works.*
Hendon Station.
Retort House, etc.

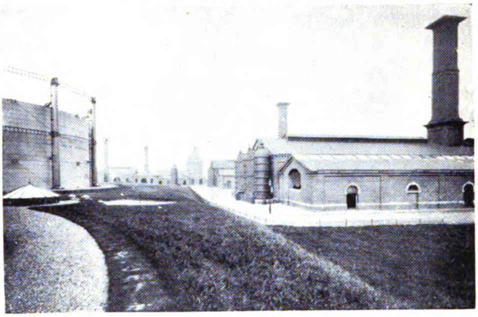
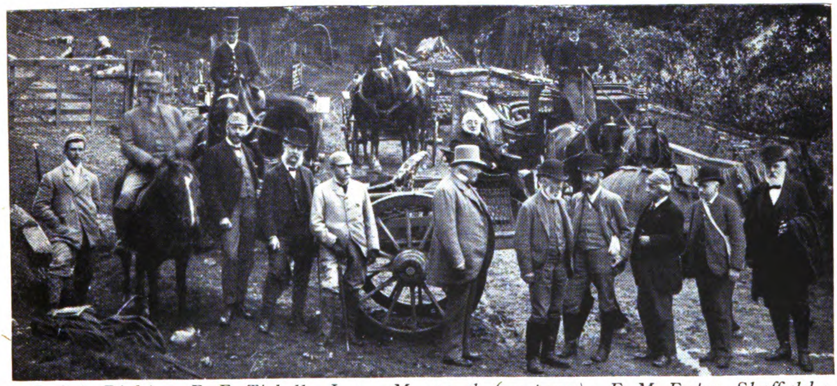


Fig. 7. *The Elan Valley previous to commencement of Birmingham Water Works.*



Left to Right :—R. E. Tickell ; James Mansergh (on pony) ; E. M. Eaton, Sheffield ; Wm. Morris Gale, Glasgow ; Henry Rofe ; Sir F. Bramwell, Bt. ; Thomas Hawksley (in chair) ; G. H. Hill, Manchester ; J. W. M. Topley (Geologist, late of Royal School of Mines) ; Charles Hawksley ; Prof. W. Boyd Dawkins ; R. K. Gray (Late Engineer, Corporation of Birmingham.)

Fig. 8. *Cornish Engine, 1827.*

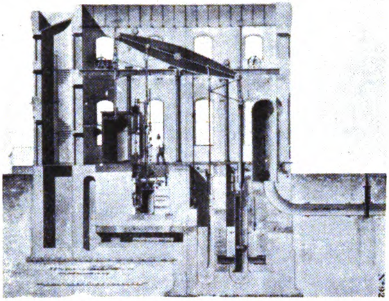


Fig. 9. *Pumping Engines, Hammersmith. Metropolitan Water Board.*

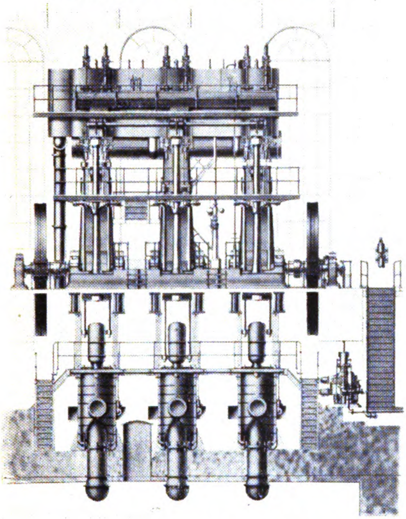


Fig. 16. *Overshot Wheel at Laxey, Isle of Man, 1854. (Robert Casement.)*

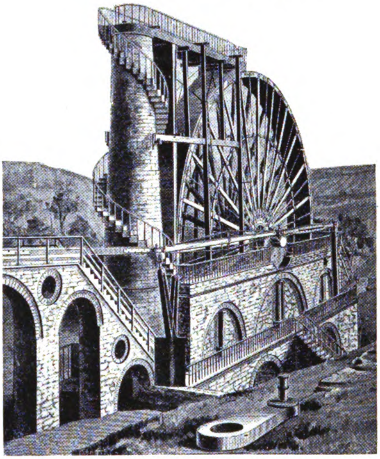
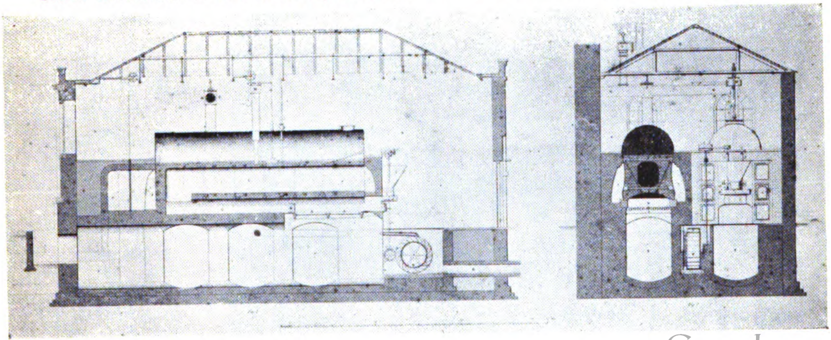


Fig. 17. *Mechanical Stoking Water-Wheel. Boulton and Watt Wagon-head Boilers, 1842. East London Waterworks, Old Ford. Thomas Wicksteed, Engineer.*



Mechanical Engineers 1913.

Power-Station, Siagne, France. *Showing lower portion of Pipe-Line.*

Fig. 18. *Old Pipe-Line.*

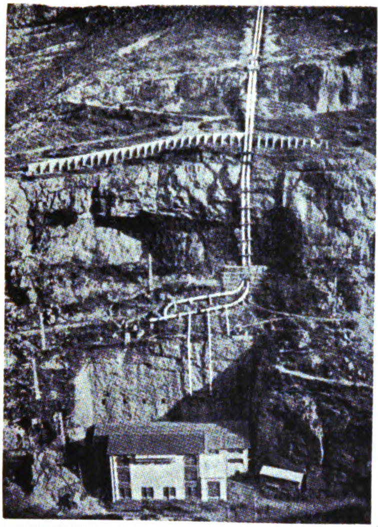
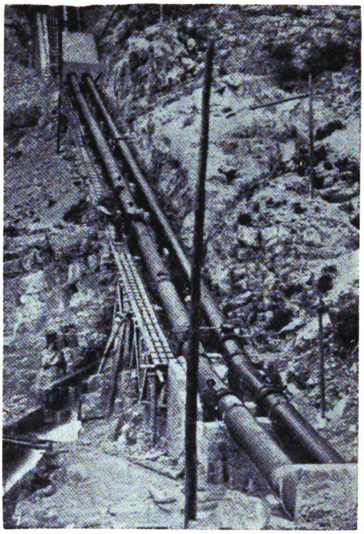


Fig. 19. *New Pipe Line.*



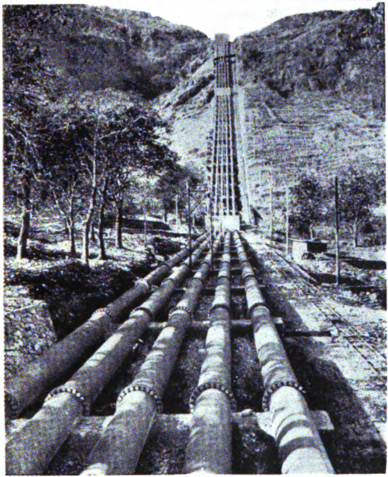


Fig. 20. *Power Station, Brusio, Switzerland. Main Anchorages.*

(For other large Hydro-Electric Power-Stations see I. Mech. E. 1911, Part 3.)

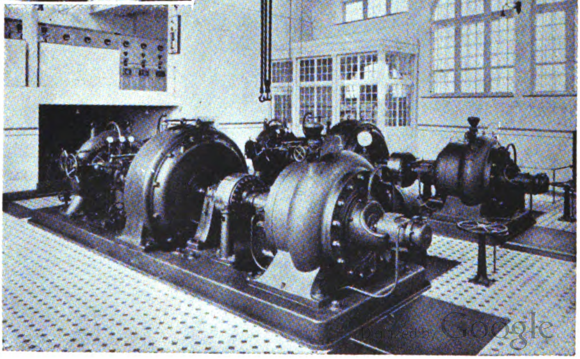


Fig. 21. *Electricity Works, Schaffhausen, Switzerland.*

Water-Accumulating Plant.

Mechanical Engineers 1913.

WATER AS A MECHANICAL AGENT. *Plate 40.*

Hydro-Electric Power-Station at Chester.
Figs. 23 and 24. *General Views.*

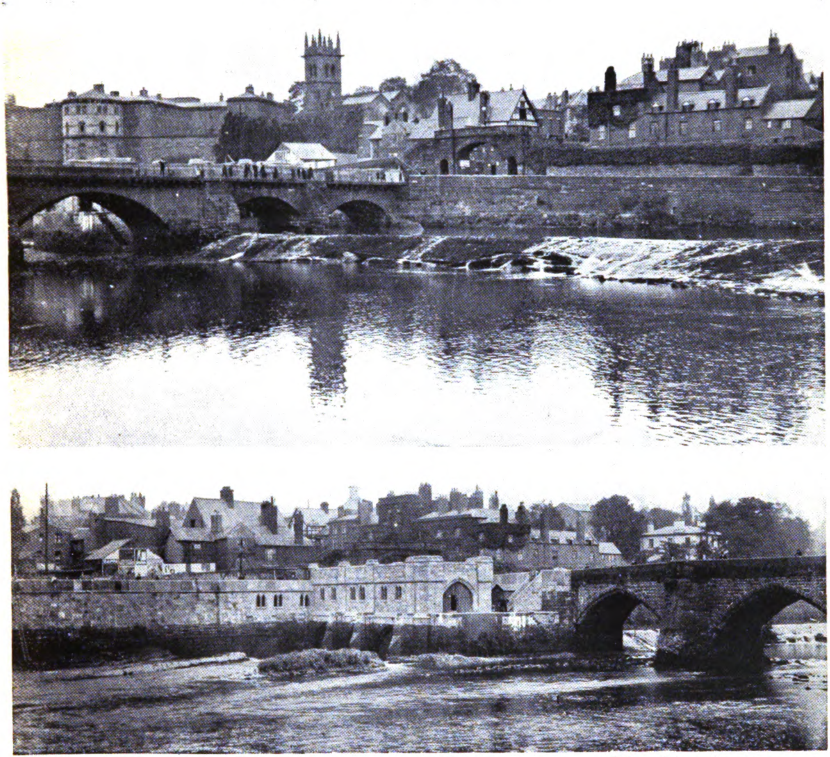


Fig. 25. *Interior of Power House.*

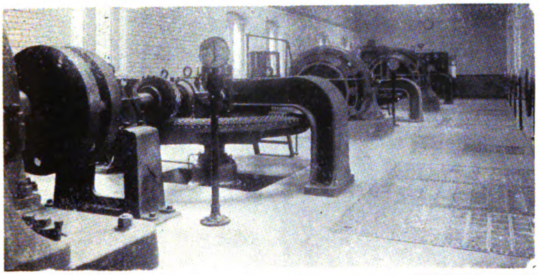


Fig. 26. *Francis Turbine Runner.*

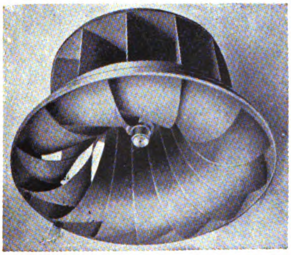
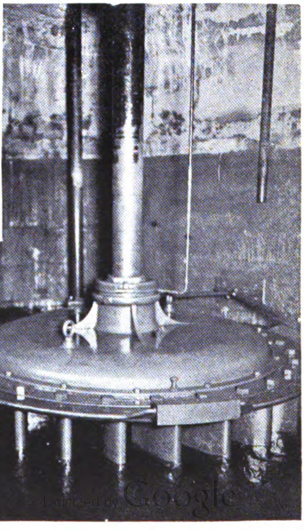


Fig. 27. *Turbine, will pass 20,000 cu. ft. of water per min.*



Mechanical Engineers 1913.

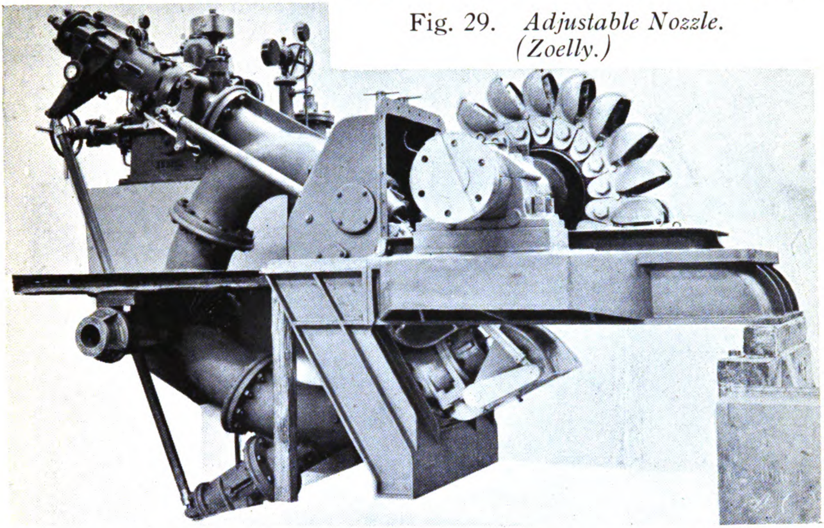


Fig. 29. *Adjustable Nozzle. (Zoelly.)*

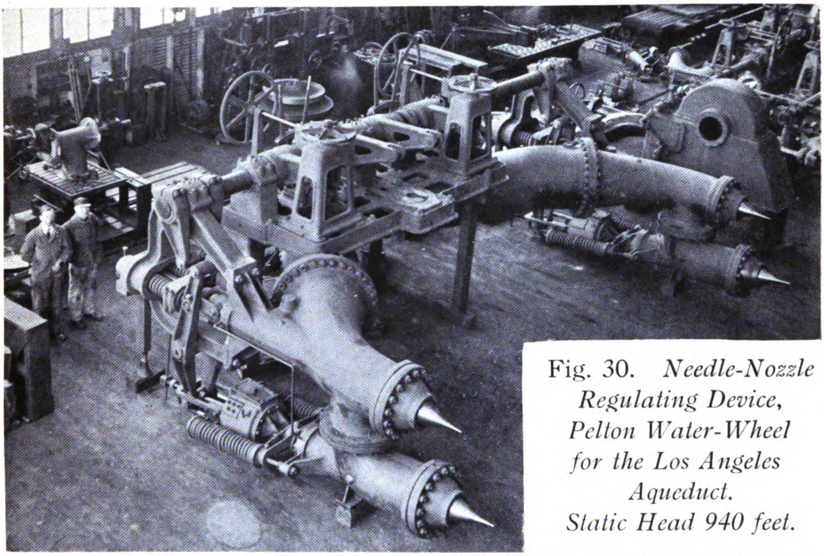


Fig. 30. *Needle-Nozzle Regulating Device, Pelton Water-Wheel for the Los Angeles Aqueduct. Static Head 940 feet.*

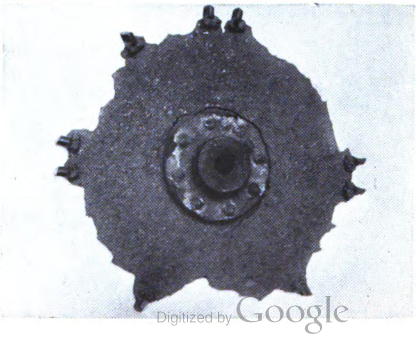


Fig. 31. *Pelton Wheel 12" diam. after making 1,200,000,000 revolutions, without any repairs. It was doing good work when removed.*

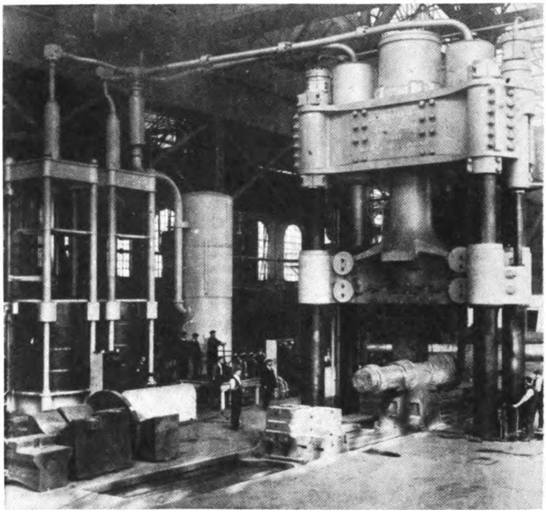
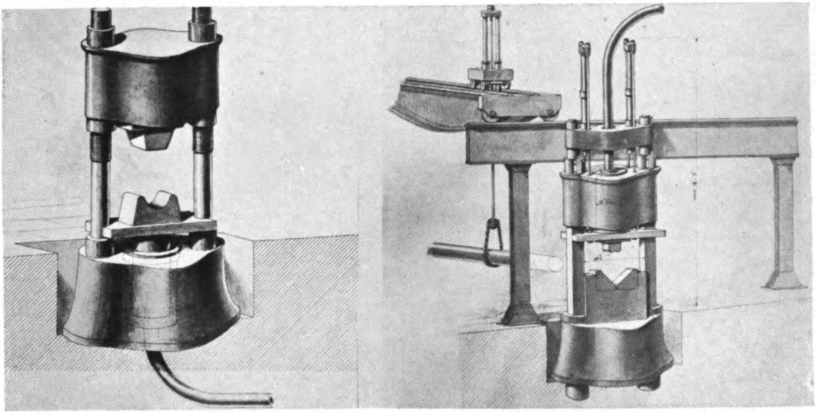


Fig. 32.
6,000-ton Hydraulic Forging Press, 1912.



Figs. 33 and 34. *800-ton Whitworth Hydraulic Forging Press.*
As First Constructed.

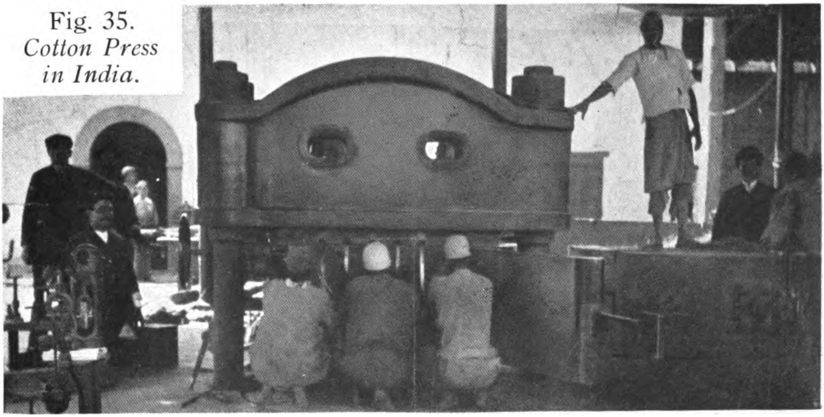


Fig. 35.
Cotton Press in India.

ROAD CONSTRUCTION.

Plate 43.

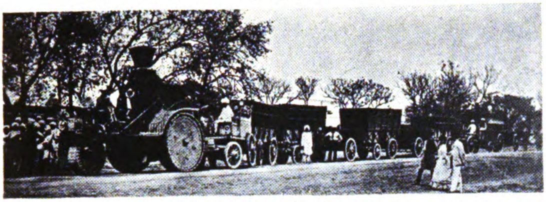
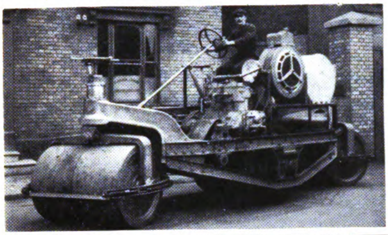


Fig. 1. *Indian Engine and Train, 1879.*

Fig. 2. *Taking a Road Measurement. (Strained wire method.)*

Fig. 5. *Three-Axle Roller. (See also Fig. 11, page 1270.)*



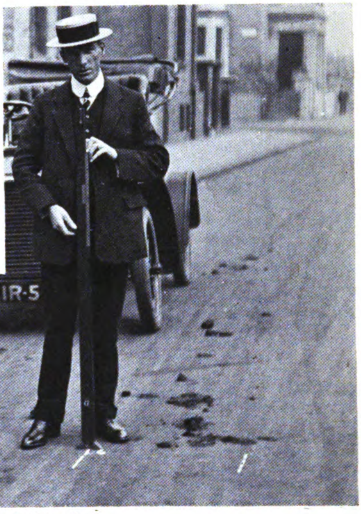


Fig. 6. *Portable Straight-edge.*

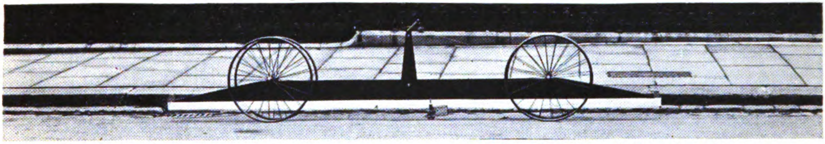
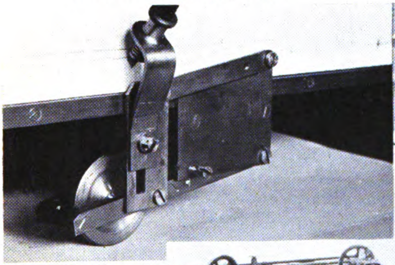
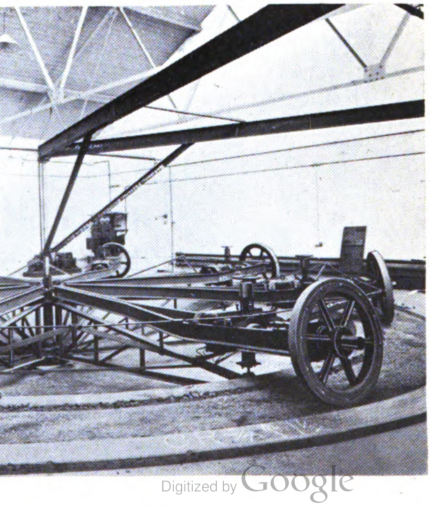


Fig. 7. *Pen Carriage on Straight-edge, Fig. 6.*

Fig. 8. *Road-Construction Testing Machine. (N.P.L.)*





ROAD CONSTRUCTION.

Drying and Mixing Machinery (Ransome-verMehr).

Fig. 19. *Combined Stone-Drier and Mixer.*

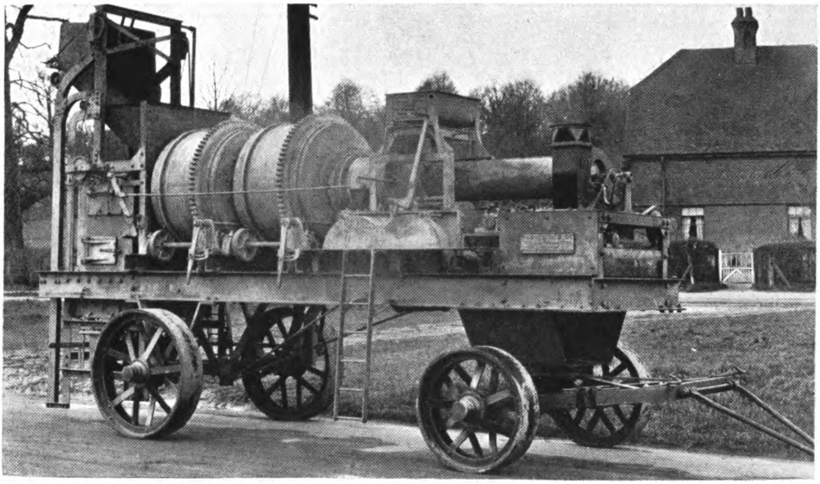


Fig. 20. *Stone-Drier*

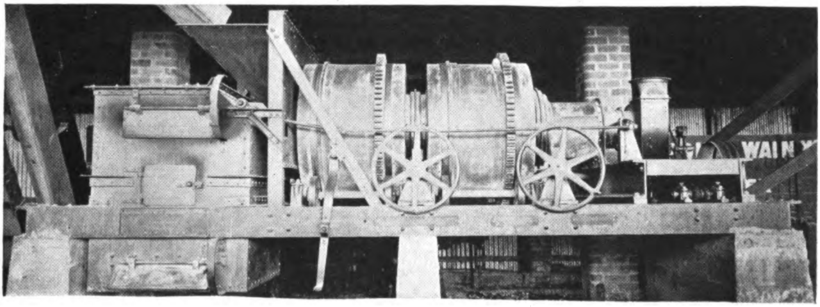
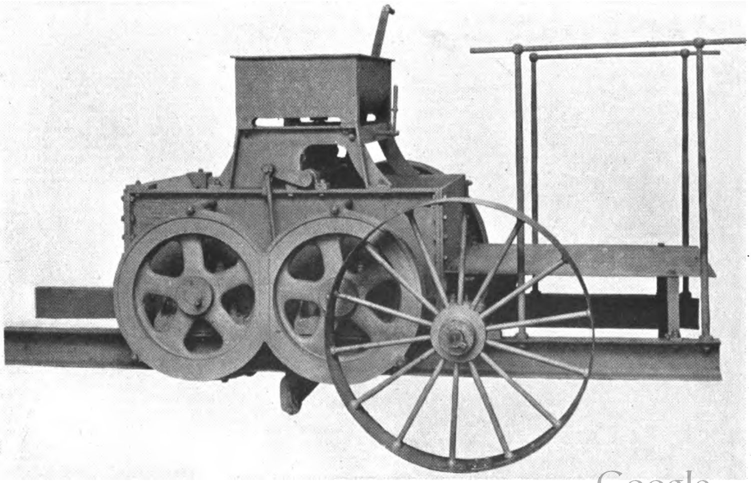


Fig. 22. *Double-Shaft Mixer.*



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